AFCRC Technical Report 53-28

GEOPHYSICAL RESEARCH PAPERS

No. 23

FORECASTING RELATIONSHIPS BETWEEN UPPER LEVEL FLOW AND SURFACE METEOROLOGICAL PROCESSES

J. J. GEORGE

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Geophysics Research Directorate
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ABSTRACT

Empirical methods of practical forecasting are designed and developed for use in the following: the prediction of cyclogenesis in the eastern portion of the United States, applicable to warm cyclones only; the prediction of track, speed and future intensity for certain classes of cyclones already established; the speed and track of cold anticyclones over the entire United States and southern Canada; and the 24-hour future position of cold fronts over the United States east of the Rockies.

Classification of cyclones has been made according to the direction of past movement and the direction of the upper currents above the cyclones. Cold fronts are divided into two categories according to their orientation; east-west types are further subdivided according to the area in which they are located.

All final forecasting diagrams show the distribution of data used to construct them. Essentially all prediction methods have been tested with independent data and the results are shown. Tables showing complete data are included as appendixes.

ERRATA*

In INTRODUCTION Section:

Page No.	Section	Errata
15	1.1 3rd line	Delete "which also indicates location of each cyclone in the data sample for Category I cyclones."

In CYCLOGENESIS Section:

34	1.5 para. 3	Change "Fig. 10" to"Fig. 13."
37	Fig. 15 legend-line 6	Should read "(Fig.16) as zero unless..."
50	4. line 4	after "p. 29" add "and p. 33."
50	6.	Change "east" to read "E. S. T."
50	11. line 3	Change "east" to read "E. S. T."

In CATEGORY I CYCLONE Section:

51	1.1 1st para.	After "winter season." add "An example of this type low is shown in Fig. 1(a)."
60		Before "STAGE I" insert "Fig. 38."
60		Before "STAGE II" insert "Fig. 39."
61		Before "COMPOSITE GRAPH" insert "Fig.40."
61	Legend	Delete "open circles with etc." and change to read "N represents cyclones which did not fill etc." Delete "filled circles with etc." and change to read "numerals represent filling cyclones and number of hours till filling."
61	Legend - Stage 2	Add "700 mb AMPLITUDE - the maximum latitude difference of the contour over the low from the ridge west to the trough east."
65	2. 1st line	Delete "X" in the 850 column and place just before "24" so as to read ".... X 24 ."
70	Line 5	Change "Section 1.34" to read "Section 1.33."
75	1st para. line 3	Delete "and 62."
75	1st para. line 3	Remove paren after "Fig. 39" and place at end of sentence.

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*George, J. J., R. D. Roche, H. B. Visscher, R. J. Shafer, P. W. Funke, W. R. Biggers, and R. M. Whiting (August 1953), "Forecasting Relationships Between Upper Level Flow and Surface Meteorological Processes," Geophysical Research Papers No. 23, Geophysics Research Directorate, Cambridge, Massachusetts.

Page No.	Section	Errata
78	Within box that begins "If curved anticyclonically etc.," change "p. 30" to read "p. 69."	

In CATEGORY II CYCLONES Section:

Page No.	Section	Errata
80	1st para.	Change "Fig. 49" to read "Fig. 1(b)."
81	2.43	Change "p. 56" to read "pp. 58-59."
84	Fig. 54	Add following legend to Figure: " • - fill-to-trough ◐ -fill ○ - no change ⊙ - deepen "

In CATEGORY IV CYCLONES Section:

Page No.	Section	Errata
99	1.5 para. 2	The words "in Appendix VI" should be "on page 20."
101	Fig. 67 Caption	Words "Appendix VI" should be "table on page 20."
103	Line 2 of text	Words "in Appendix VI" should be "on page 20."
117	1.64 Para. 1	The words "in Appendix VI" should be "on page 118."

In DISPLACEMENT OF SURFACE COLD FRONTS Section:

Page No.	Section	Errata
134	Work Sheet for Category ONE Cold Front	Include as requirement three, criteria 2 under "Method," page 126.
142	Figure 97	The geographical background, latitude and longitude lines except for the 100th meridian should not appear on this figure.
142	Figure 97 Legend	Add "The dashed lines connect double low centers."
151	Under "Development"	Step 3 - to correct the height difference for latitude refer to latitude correction table, page 20. Step.4 - to correct the height difference for latitude refer to the latitude correction table, page 20.
183	Appendix VII Table 2	Label 4th column "$\Delta \phi N$" Label 5th column "$\Delta \phi W$" Label 6th column "AF700"
185	Appendix VII Table 4	Label 6th column "ΔT 850"

FOREWORD

This paper presents the results of some two years of investigation by a group of Eastern Air Lines meteorologists under the direction of J. J. George. These investigations were performed under contract with the Geophysics Research Directorate of the Air Force Cambridge Research Center, Air Research and Development Command, and were aimed at providing solutions to some important problems of short-range weather forecasting. The quarterly progress reports of this project indicated that practical and objective solutions were being obtained. These results, though in some respects incomplete and unrefined, were immediately useful to the short-range forecaster.

Only limited distribution was made of the quarterly reports, and soon the demand for copies far exceeded the number available. This paper was written to consolidate and to make the results of the investigations more generally available. It is published, however, for technical information only and does not represent recommendations nor conclusions of the sponsoring agency.

All sections of the paper reflect the viewpoint of the forecaster; all elements of the solutions are easily measured values available in any forecasting office. Theoretical considerations played a part in defining the strategy of the attack, but the forecasting rules given are completely empirical and were, without exception, dictated by the data.

A wide variety of measurements or parameters were used because the diversity of the forecasting problems necessitated this situation even though attempts were made to establish common tools for forecasting. In accordance with the problems of the forecaster, all sections of the paper deal basically with "winter" weather over the United States. The data samples were confined to the months of November through March. Tests have not been made to determine the applicability to other months nor to other areas.

This paper should not be construed as a complete answer to the various prognostic problems. It is believed, however, that the forecasting devices described will result in a measurable increase in the accuracy of short-range weather prediction.

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ILLUSTRATIONS (Continued)

FORECASTING RELATIONSHIPS BETWEEN UPPER LEVEL FLOW AND SURFACE METEOROLOGICAL PROCESSES *

INTRODUCTION

From its inception, this research has had as its goal the investigation of objective forecasting methods necessary to the preparation of short-range prognoses of the dominant meteorological systems normally found on a surface weather chart. With a view to later integration of the methods into a standard procedure for preparation of a short-range surface prognostic chart, this research has been separated into independent sections: the investigation of the process of cyclogenesis; the development and movement of cyclones; the movement of anticyclones; and the behavior of cold fronts.

At the start of this study, it was apparent that there were several basically different types of cyclones. The differences were best resolved by dividing the cyclones into four categories depending upon two criteria: the past track of the cell, and the direction of the flow aloft over the cell. Different forecasting methods were developed for each category of cyclone. Since nearly all cyclones dealt with in this study were warm ones, the authors did not attempt to classify cyclones into warm or cold types.

1.1. CATEGORY I CYCLONES

Category I cyclones are those that have been moving from the northwest quadrant and are located beneath northwest flow at 700 mb. Generally the flow is occurring in a broad belt with no sensible departures from the pattern in the vicinity of the low cell. An example is shown in Fig. 1(*a*), which also indicates the location of each cyclone in the data sample for Category I cyclones.

1.2. CATEGORY II CYCLONES

Category II cyclones are those that have been moving from the northwest quadrant and are located under southwest flow aloft which is produced by a perturbation in a basically northwest contour pattern. Figure 1(*b*) illustrates this type.

1.3. CATEGORY III CYCLONES

Category III cyclones are those that continue moving from the northwest quadrant although located under southwest flow at 700 mb due to the presence of a major trough at that level. Figure 1(*c*) depicts a typical upper air pattern with a Category III cyclone.

Figures 1(*b*) and (*c*) indicate certain amplitude measurements of the upper air contour pattern; these provide an objective method of determining whether the trough is a perturbation or a major trough. Refer to page 80 for details of this method.

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* Manuscript received for publication 7 November 1952.

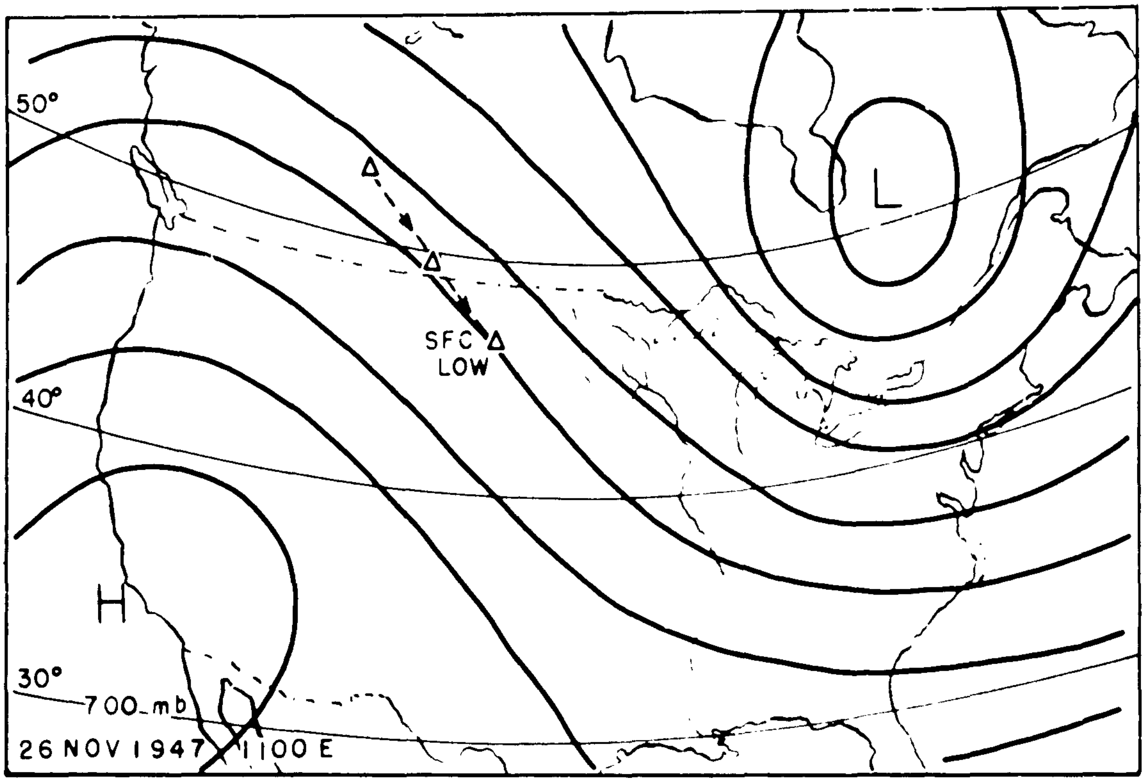

Fig. 1(*a*). Example of typical 700-mb circulation pattern associated with Category I cases (pure northwest flow).

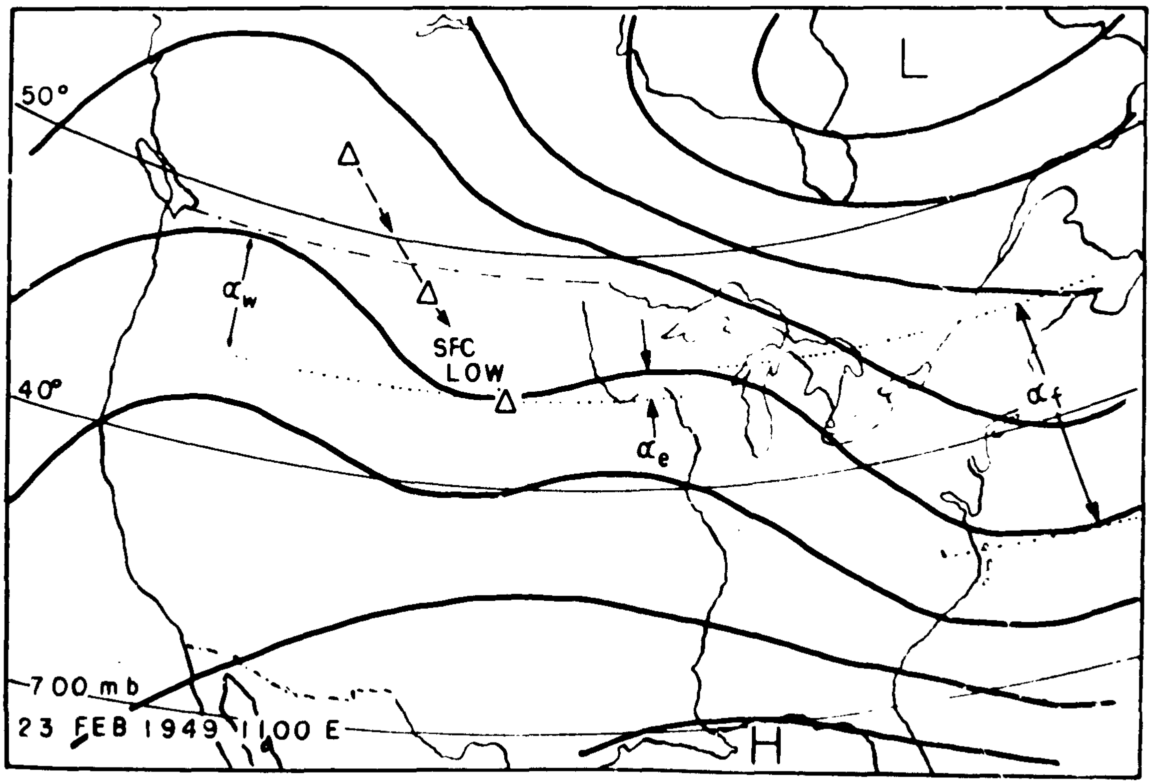

Fig. 1(*b*). Example of typical 700-mb circulation pattern associated with Category II cases (perturbation). In this case, α_w is 4°; α_e 2°; and α_f 8°.

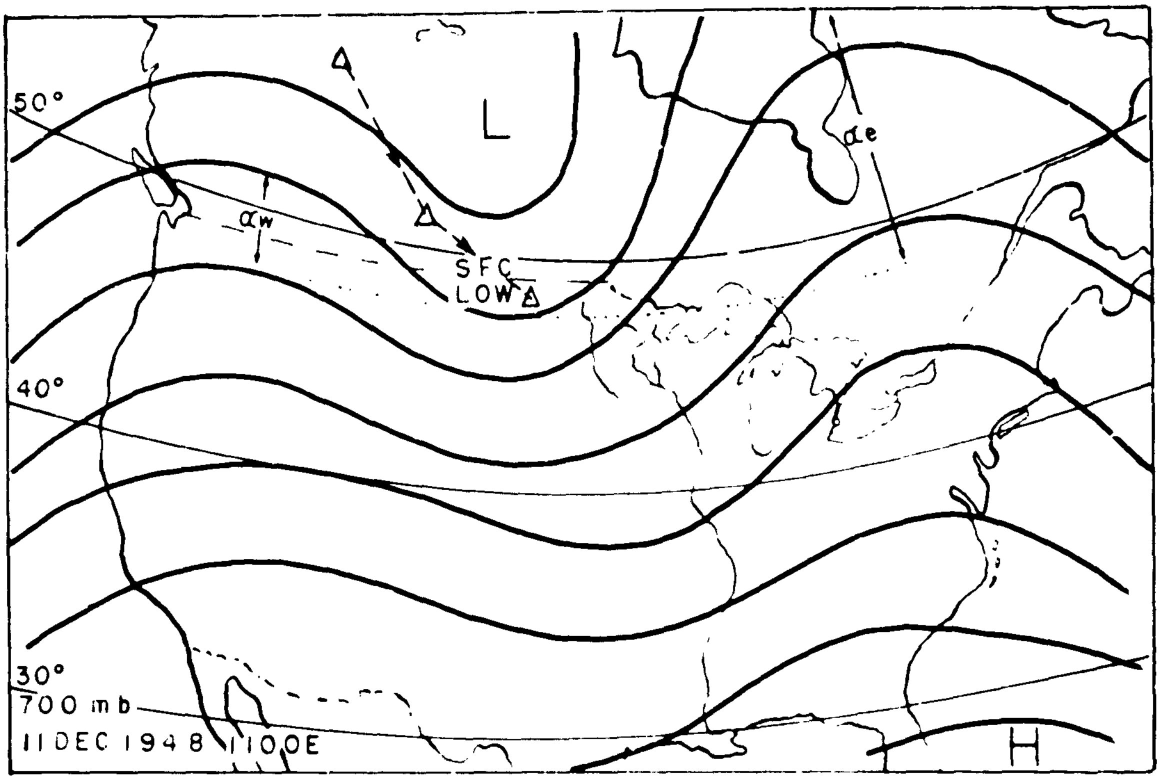

Fig. 1(*c*). Example of typical 700-mb circulation pattern associated with Category III cases (effective trough). In this case, α_w is 4°; α_e 25°; and α_f 13°.

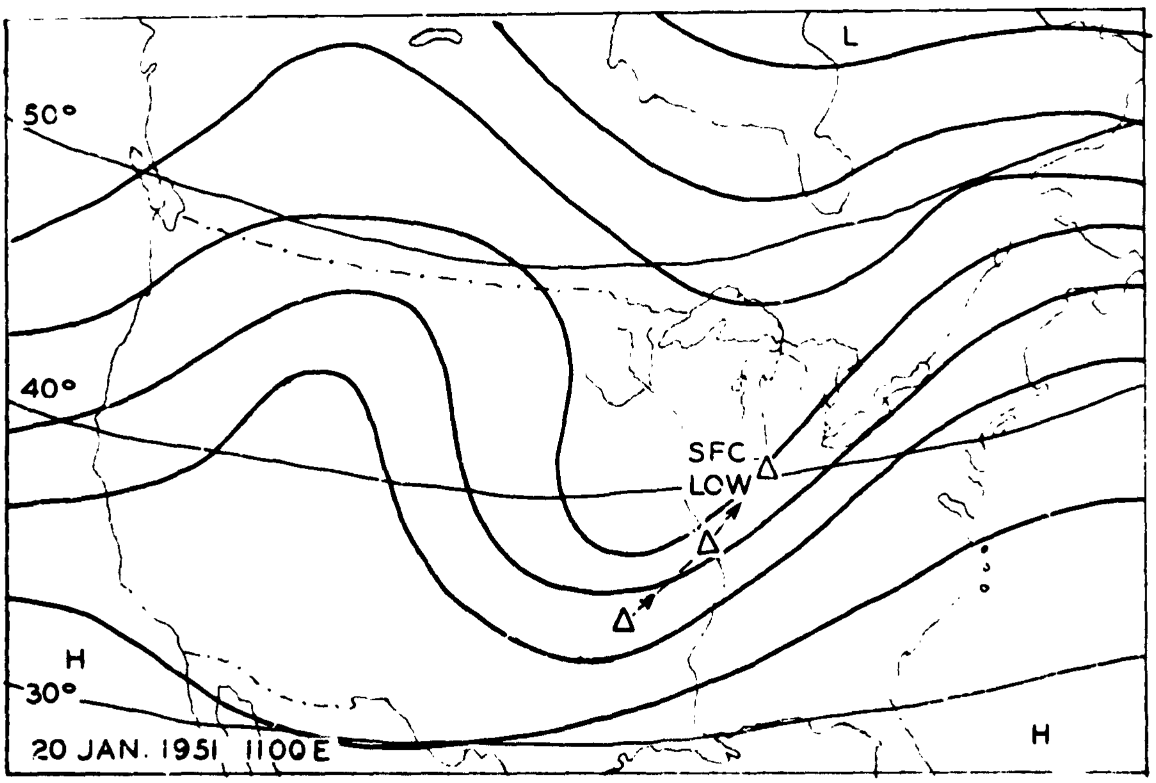

Fig. 1(*d*). Example of typical 700-mb circulation pattern associated with Category IV cases.

1.4. CATEGORY IV CYCLONES

Category IV cyclones are those that have been moving from the southwest quadrant and are located beneath southwest flow aloft. Figure 1(*d*) shows a typical pattern.

It is important that the forecaster be familiar with this cyclone classification because the initial step in forecasting the behavior of any cyclone is to place it into one of these four categories. However, not all cyclones can be so classified; an occasional cyclone moving out of the northwest, for example, and located immediately under a 700 mb trough cannot be identified with either a belt of northwest flow or southwest flow. Also, a few surface systems with predominantly west-to-east flow aloft cannot be included in the categories. No treatment of these types has so far been undertaken by this project.

Although cyclones in Categories I through IV make their initial appearance in western North America, all lows which originate from cyclogenetic processes in the eastern United States almost invariably are born in Category IV. Nevertheless, these four categories of cyclones are not always independent of each other but are frequently time-related. A cyclone under northwest flow moving from the northwest may pass successively through Categories II and III, and thence to Category IV. It is not always possible to trace this development. Once the cyclone leaves Category I, the development may be so rapid that an upper air chart taken 12 hours later will show the cyclone as Category IV. There is evidence, however, to support the belief that many cyclones follow a life cycle through all four categories.

1.5. INTENSITY MEASUREMENT OF CYCLONES

Since the inception of this research, there has been considerable discussion of intensity measurements. Since deepening and filling are to be predicted through the use of objective tools, it is imperative that quantitative and objective measurements of intensity be obtained. The traditional use of central pressure as a gage of intensity has been abandoned because for certain types of cyclones central pressure falls concurrently with a decrease in the cyclonic circulation. Several other measurements have been discarded for similar reasons.

Since cyclonic circulation is being discussed, it appears that the most desirable gage of intensity will be one which is a measure of the strength of this circulation, namely, the pressure gradient. A prime requisite for comparison of intensities of numerous cyclones is that the circulation of these lows be measured over a standard area. The method for determining the intensity which has been developed in this study defines this area as a circle of 600 miles radius, using as a center the center of symmetry of the inner isobars of the cyclone. The objective procedure is to measure the pressure differences in millibars between the center of the cyclone and the four cardinal directions at points 600 miles from this center. The average pressure difference is then computed, and this average difference is defined as the *intensity count* of the low. These counts vary from 2 to 40, with the average intensity near 14. There will be occasional measurements in which the 600-mile distance will exceed the distance to a ridge line. In these cases, only the maximum pressure difference is to be used.

There are, of course, weaknesses in the method, but after considerable trial this appears to be the most satisfactory objective measure of cyclonic circulation.

1.6. MEASUREMENTS AND DATA

The methods to be described consider surface pressure systems only at 0130E and 1330E and upper-level charts at 1000E and 2200E. The 3-hour time lag between the upper-level data and the surface data

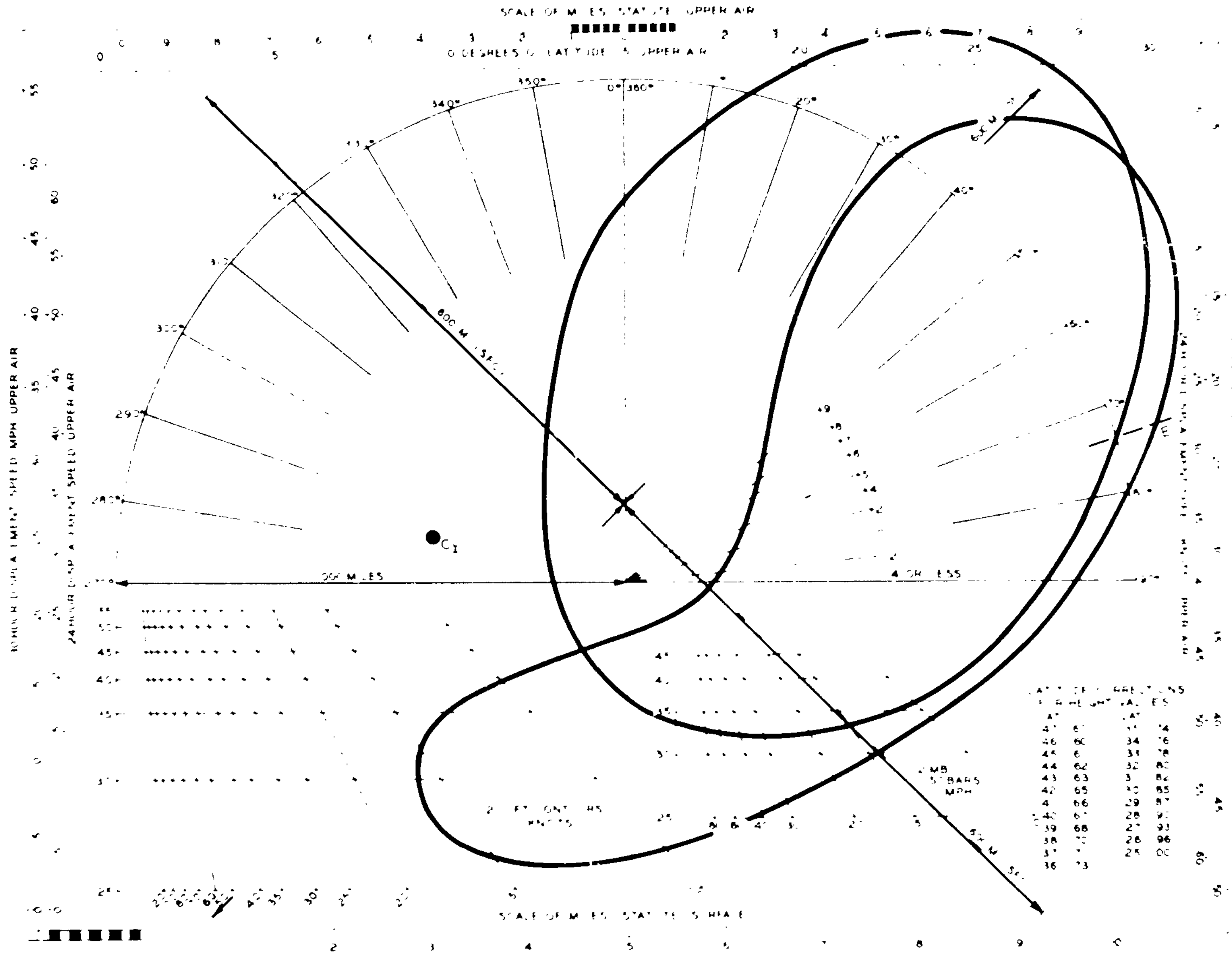

Fig. 2. A composite measuring tool. This is a facsimile of a composite overlay designed for use on a Lambert Conformal Projection with standard parallels at 25° and 18° 30'. It is presented as a suggested basic design and, for Lambert Conformal Projections meeting the standard parallel requirement, may be photographically enlarged to the proper map scale.

has been incorporated into all forecasting parameters, so that interpolation of pressure system positions is unnecessary. The starting time of all forecasts is the time of the surface synoptic data, 0130E and 1330E.

In all measurements of geostrophic wind, the standard geostrophic windscale should be used (without correction for curvature). When contour height differences were measured, it was found empirically necessary to apply corrections, multiplying by the proper latitude factor listed below.

Latitude Corrections for Height Values

Lat.	Factor	Lat.	Factor
47	.60	34	.76
46	.60	33	.78
45	.61	32	.80
44	.62	31	.82
43	.63	30	.85
42	.65	29	.87
41	.66	28	.90
40	.67	29	.87
39	.68	28	.90
38	.70	27	.93
37	.71	26	.96
36	.73	25	1.00
35	.74		

In the practical application of these forecasting methods, the meteorologist must measure many of the parameters on a weather map, and occasionally in different units. The use of properly graduated rulers facilitates these measurements. In some sections of this report, the delineation of specific areas is essential; this can best be accomplished by the use of a template or overlay. Figure 2 illustrates an overlay, combining linear measuring rulers in different units, angular measurements, geostrophic wind scales, and area delineation templates; this overlay may be photographed and enlarged to the scale of any Lambert conformal conic map.

All of the basic research data has been obtained from the map files of Eastern Air Lines, Inc. All charts have been labeled using Eastern standard time. The geographical limits of the base chart include the North American continent, excluding Alaska and Canada north of the 67th parallel, but including the Caribbean Islands. The projection is Lambert conformal conic with standard parallels at 25° and 48°30′. The scale of the base surface map is 1:7,500,000, and of the upper-level chart 1:15,000,000.

THE PREDICTION OF CYCLOGENESIS

JOSEPH J. GEORGE

1.1. INTRODUCTION

The derivation and production of the energy that drives an extratropical cyclone is extremely complex. There can be little doubt, however, that when two air masses of different densities are brought into juxtaposition at the same altitude, the potential energy is favorable to the formation of new cyclones. It therefore follows that indications of this kind of cyclogenesis should be sought at levels where both cold and warm air masses exist. Since cold masses are relatively shallow in the eastern United States, attention should be focused on the lowest standard level above the surface, that is, 850 mb. Although the data in this study have been gathered for higher levels, the results emphasize that cyclogenesis in the eastern United States can best be predicted from the conditions met at the 850-mb level. Indeed, for the particular geographic area involved, in all but a few cases, it can apparently be done only from the 850-mb level. There is a fundamental difference between the cyclones born in the eastern United States and those in certain other regions, notably the Mediterranean and southwest United States. The former are almost invariably warm and shallow at birth, whereas the latter are predominantly cold deep lows. Methods of forecasting the formation of cold lows have not been attempted in this paper.

Even if the conclusion that the prediction of warm cyclogenesis must be accomplished with reference only to low levels is valid, it does not necessarily follow that the actual pressure reduction involved is contributed entirely, or indeed, in large parts, by the low level processes. It is not a subject which will be pursued here; the only objective of this paper is to determine means of forecasting cyclogenesis regardless of the physical processes which produce it.

To date, the geographic area in which cyclogenesis has been studied has been confined to the latitudes of the United States between longitudes 70 and 100° W. The effectiveness of the method for forecasting cyclogenesis described in this report, lies in the recognition by the forecaster of certain patterns in the upper level charts. It is conceded that subjectivity is involved in the recognition of a pattern, nevertheless, the particular pattern preceding cyclogenesis is quite well defined and especially for really significant cyclogenesis, can hardly be mistaken.

In discussing meteorological patterns, illustrations are infinitely more effective than descriptions. The presentation of a number of actual examples should quickly acquaint the reader with the appearance of the patterns so that they become easily recognizable. Accordingly, this section will contain a maximum of illustrations.

The patterns, although not unduly sensitive, require that as much care be exercised by the analyst in drawing isotherms as a careful meteorologist gives to the placing of contours. Not all analysts, by any means, are in the habit of placing this much emphasis on isotherms; and attempts to use charts which have not been checked for accuracy may well lead to unnecessary errors.

The data for this study consisted of the winter months of November, December, January, February and March for the four winters from 1947–48 through 1950–51. In that period, 258 case histories, including negative cases, were collected and studied. Eastern standard time is used throughout. These data are included in Appendix I.

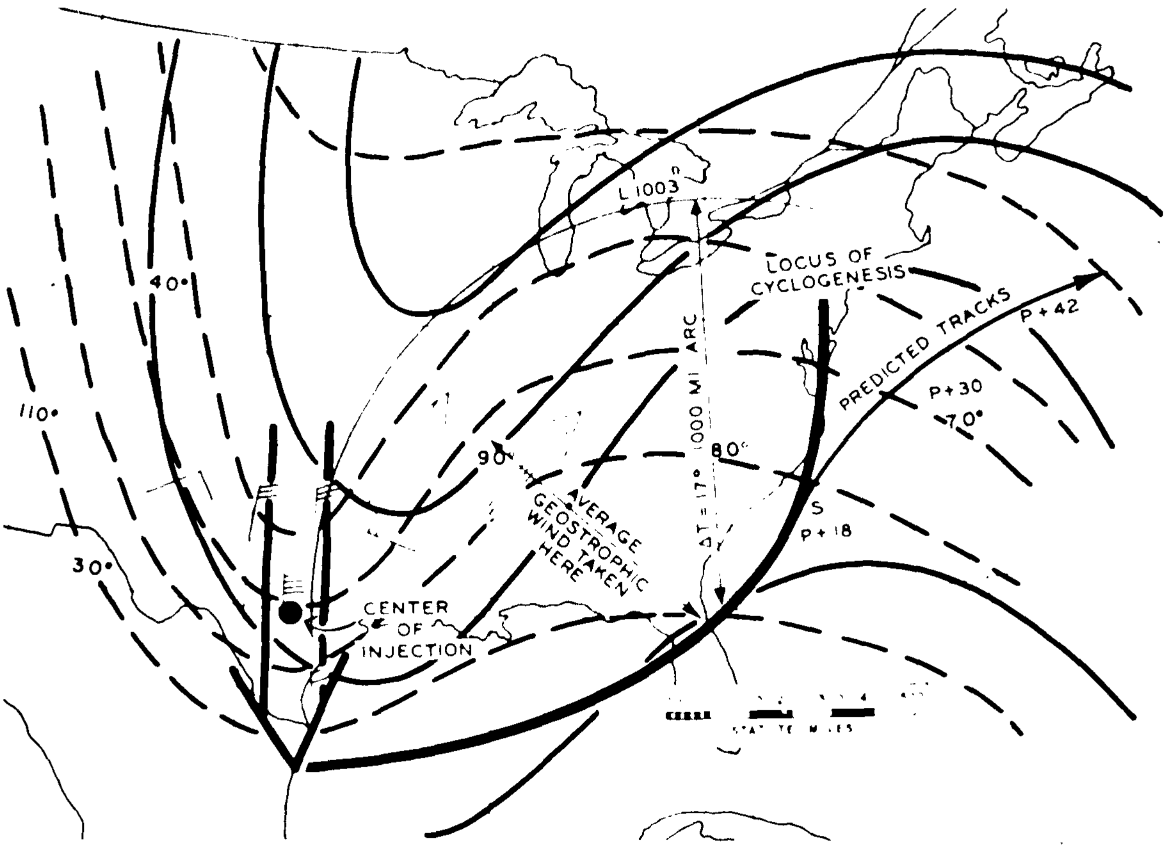

Fig. 3. The basic concept of factors at 850 mb used in predicting warm cyclogenesis is illustrated. The cold air injection is clearly taking place over Texas, which is the most common location. The location of the new cyclone is determined here as slightly north of east from the center of cold injection, because the isotherms are loosely packed and, of course, it should occur on the line labeled "locus of cyclogenesis." Ordinarily, timing would be for formation 18 hours after this pattern is first observed. The basic direction in which the new storm should start is given by the average of the steepest orientation of the isotherms (double shanked arrow) and the contours (triple shanked arrow). Frequently only one of these two elements is available. The track curves eastward because the amplitude of the isotherms is low. The speed parameters are: (1) the greatest temperature gradient in the northwest quadrant measured from the spot on the locus within about 300 miles of the predicted location which will give the greatest gradient. It is indicated here as ΔT. (2) A representative value of the geostrophic wind in the southwest current west of the predicted location of cyclogenesis. Here it is illustrated through Alabama and Georgia. When the southernmost contour lines around the trough lie north of the predicted cyclogenesis location, no geostrophic wind is measured and the speed of the new low is forecast as 20 mph. The average wind in this injection is about 25 knots and the thermal range is about 16° or 17°.

1.2. THE FORECASTING PATTERN

With very few exceptions, every significant case of cyclogenesis which occurred in the United States and adjacent waters east of 95° longitude during the test period was preceded by a common pattern at 850 mb. At some point along the isotherm ribbon (the belt of packed isotherms), a current becomes established which at most is usually only a few hundred miles wide and which obviously crosses the isotherm ribbon from cold to warm air. Such a current is usually associated with an upper trough and is most effective in

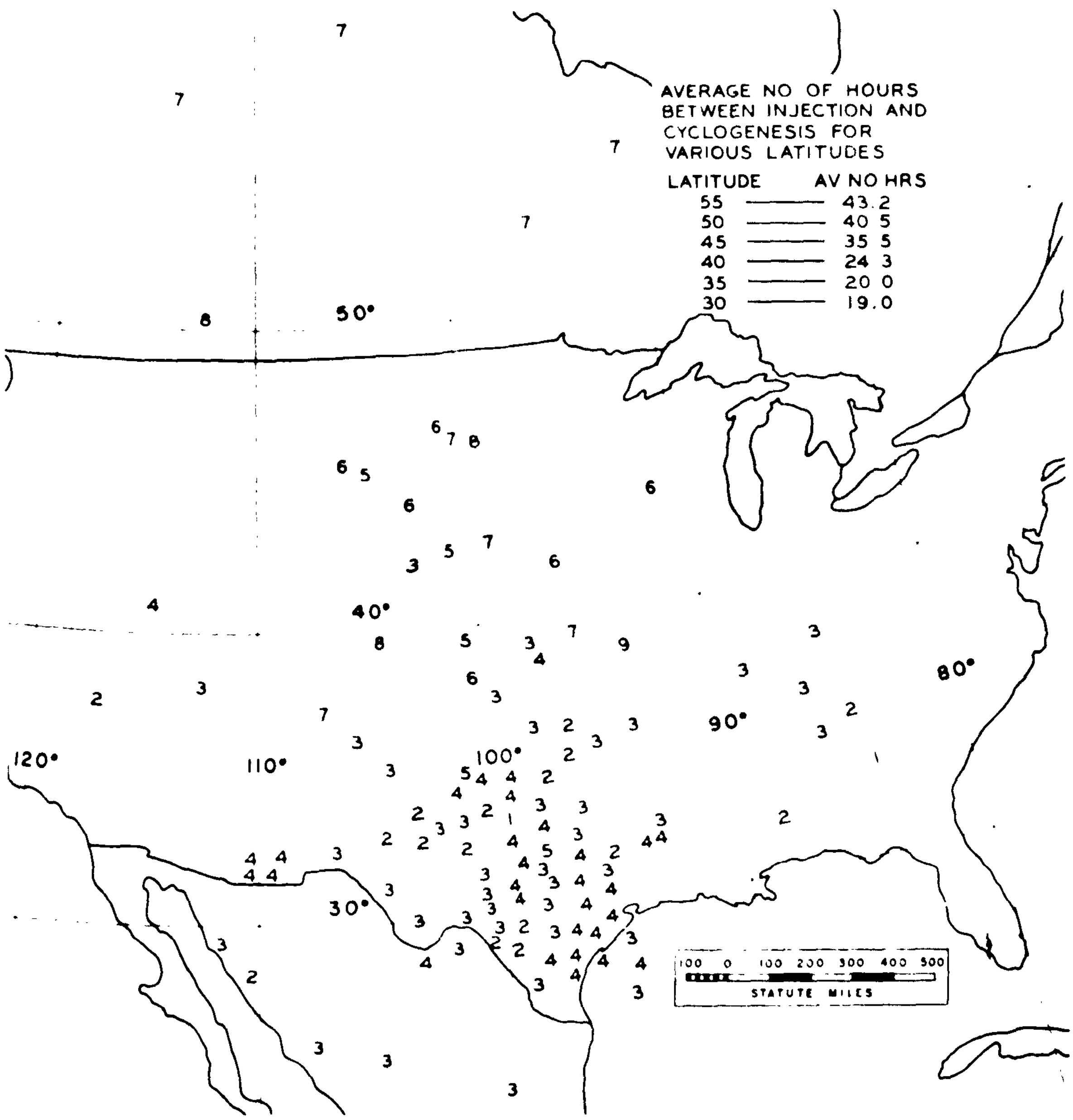

Fig. 4. The location of centers of injection. Each figure is located at center of injection and represents a number of 6-hour intervals between the time the injection was first established and the appearance of the first closed isobar of the related cyclogenesis.

causing cyclogenesis under the following conditions: when the isotherm ribbon is well to the south of 38°; when the number of isotherms crossed by the current is large; and when the current is of appreciable strength i.e., greater than 15 knots. The current is usually best delineated by actual wind reports rather than contours, because at times there is a great deal of cross-contour flow. Figure 3 shows the typical pattern.

At first it will appear that the location of a center of cold air injection is difficult and [illegible] most cases there is remarkably little chance for error. Only experience with actual cases can [illegible] on this point. The location of this center is important because to a large extent it governs [illegible] formation of the new cyclone.

Determining the time when a new cyclone will form, is of prime importance. The cold [illegible] will henceforth be called a *cold air injection*,[1] begins from 12 to 48 hours before the first closed [illegible] genesis appears and from 700 to 1500 miles upstream from the region of cyclogenesis. [illegible] interval is 18 hours and this value is used in making forecasts. Since the upper-air chart [illegible] 12-hour intervals, each case may be in error by at least plus or minus 6 hours. In actual [illegible] six hourly wind soundings may be used to check the beginning of the cold air injection, [illegible] should be forecast to occur 18 hours later.

Figure 4 is a map showing the geographical location of the centers of injection for act[illegible] cases and shows clearly that the majority of cold injections take place at southerly latitude[illegible] found that the latitude of injection is related to the time interval between injection and [illegible] follows: the interval decreases with decreasing latitude. Cases where a new center formed [illegible] terior of a well developed cyclone and subsequently became the only center are called [illegible] must be treated separately and are not shown in Fig. 4.

A cold air injection is, of course, nothing more nor less than apparent cold air advec[illegible] taking place as a current rather than as a broad scale phenomenon. When the isotherms [illegible] over perhaps a thousand miles and there does not exist a *packing* or an *isotherm ribbon* the [illegible] cyclogenesis are not usually present, even though broad scale cold advection is present.

Injections frequently are associated with surface cyclones and, of course, with 500-m[illegible] contours and isotherms are out of phase. The deeper the surface low, the more likely is a [illegible] injection, but as will be noted later, this does not mean that cyclogenesis must necessarily [illegible]

The temperature range over which the cold injection operates is found by drawin[illegible] a manner that it traverses the greatest temperature range and at the same time remains [illegible] maximum winds. The extreme temperatures which are encountered by this sect[illegible] still within the limits of the packed isotherms, constitute the temperature range. When [illegible] less than about 12° C, cyclogenesis does not occur. A range of 15° C is necessary before real [illegible] is attained. The wind (in knots) averaged over the streamline is called the average wind; it should be weighted by estimate so that more importance is assigned to the wind which crosses the more closely packed isotherms.

The center of injection lies in the middle of the strongest portion of the cross-isotherm current on the isotherm midway between the temperature extremes described in the preceding paragraph.

It is often difficult to decide whether an injection is simply a continuing one, which has previously been used to predict a new cyclone, or whether it will be associated with still another cyclone formation. A single persisting injection may produce either a series of weak waves following one another closely or it may produce a single vigorous cyclone. If the prediction of intensity (yet to be considered) is for weakness and the injection still persists after the first small center forms, the trend will be for a succession of weak waves until the intensity prediction becomes more vigorous. On the other hand, a prediction of a strong cyclone usually means that the injection will persist but that it will be associated with deepening of the new storm rather than the production of another.

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[1] This term was probably first used in connection with cyclogenesis by Oliver Wulf.

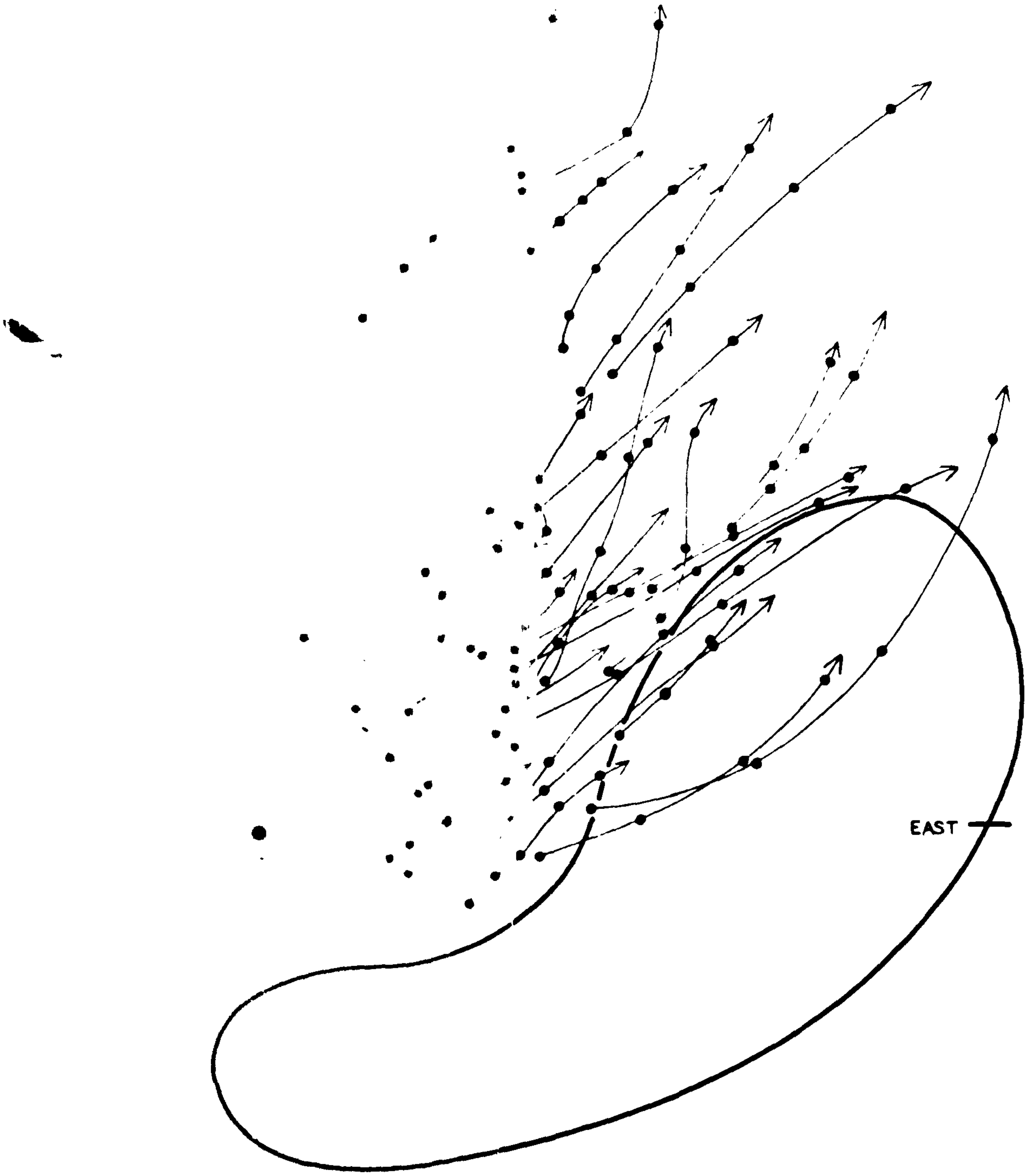


Fig. 5. Tracks of primary storms which are followed by cyclogenesis within the kidney-shaped area. Nearly all of these tracks are oriented north of 61°. Orientations are measured from the meridian nearest the position of origin in a straight line to the subsequent 18-hour position. The tracks were made by placing the dot marked C_I over the actual center of injection in each case, orienting the point marked "East" on the same parallel as C_I and tracing the 18-hour track of the cyclone which had previously been copied to the 850-mb chart from the surface charts. Of course, the forecaster will be under the compulsion of forecasting the 18 hour position since he will not have this information by the time he makes his forecast. The kidney-shaped area will be supported by data later — it is shown in these figures merely as a common reference.

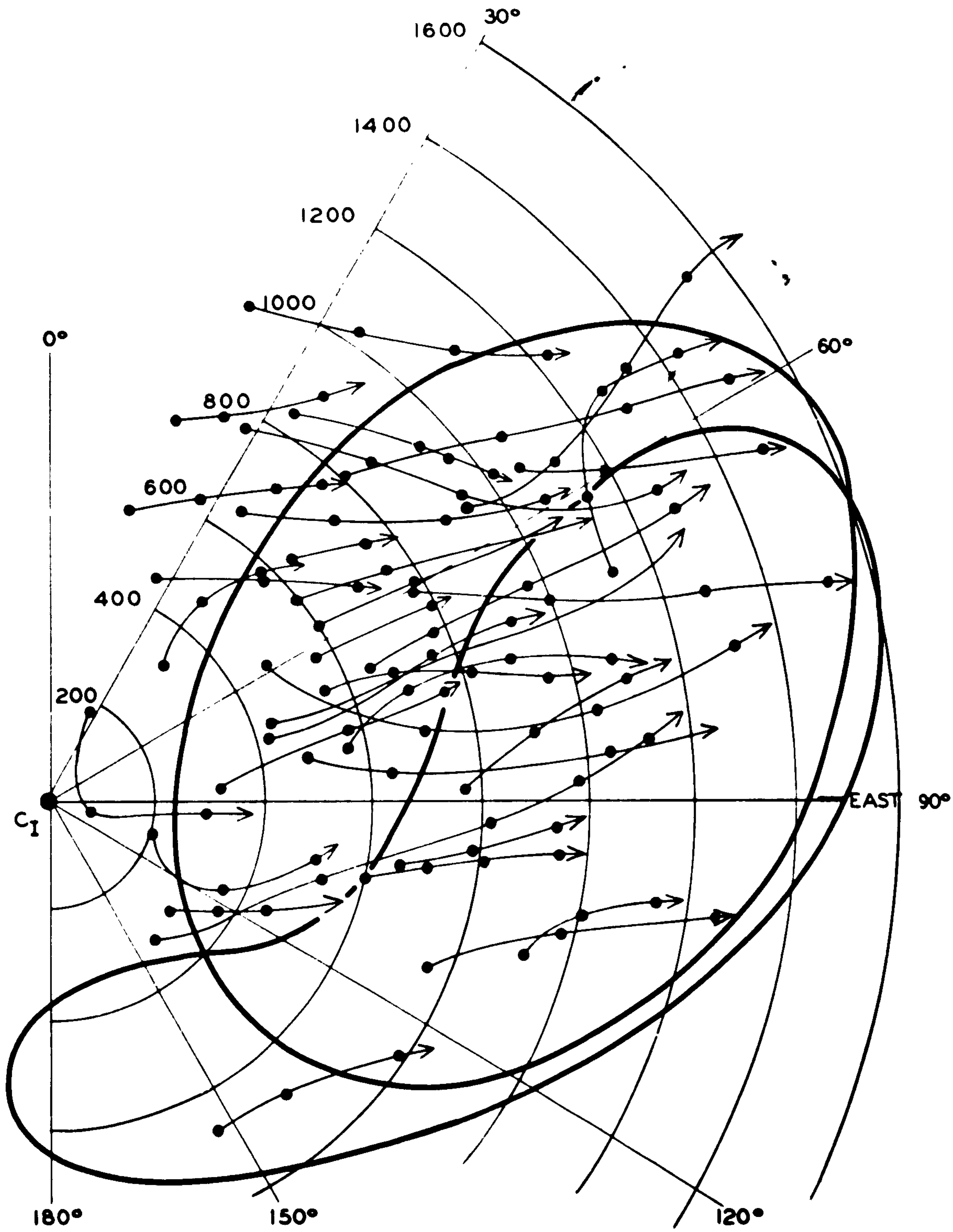


Fig. 6. The tracks of primary cyclones which underwent center jumps. Practically all of them are between 61° and 104° in orientation. (They are measured the same as those in Fig. 5.) The roughly circular area outlines the 18-hour position of nearly all the primary centers following which the jump occurred.

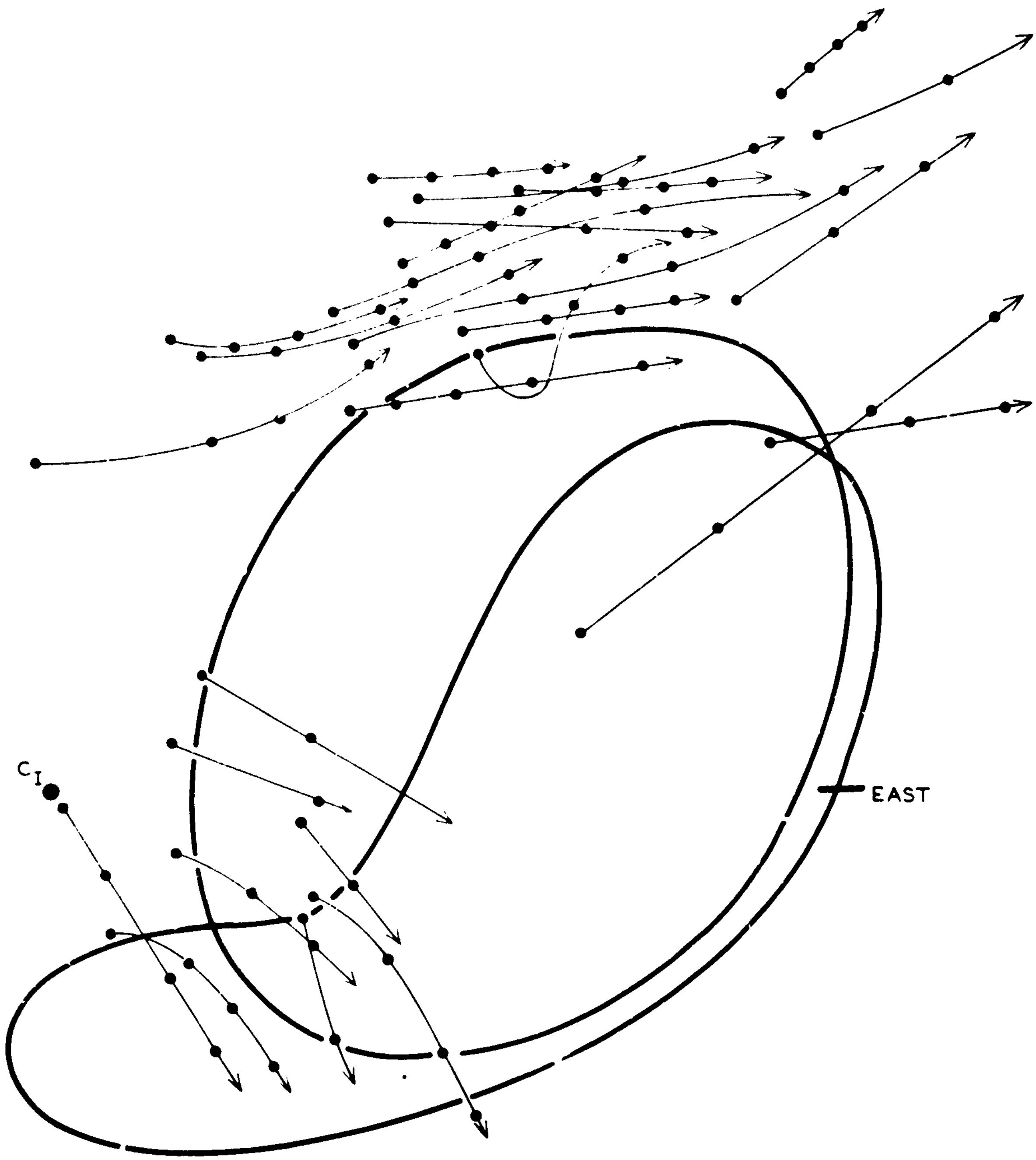


Fig. 7. The tracks of primary cyclones having tracks greater than 60° and which are associated with cyclogenesis. Compare with Fig. 6. Note the few tracks which have an 18-hour position within the center jump circle. The group of storms at the bottom are separated from center jump cases by their tracks which are greater than 104° and also most of them are filling storms.

The situation for a series of weak shortlived waves is accompanied by a very slow movement of the center of injection (less than 200 miles in 12 hours), while an intensifying cyclone has an associated center of injection which travels usually in a southeasterly direction more rapidly.

When an injection occurs, one of three things almost invariably follows: the parent cyclone deepens; a new cyclone forms; or a center jump occurs. Probably the most difficult problem for the forecaster to solve is deciding which of these three alternatives will occur. Methods will be described which will enable the decision to be made with reasonable objectivity and accuracy, but there are cases which cause difficulty, as will be shown.

A brief discussion of definitions used in this section is necessary. The term *cyclogenesis* refers to any closed isobar forming around lower pressure where none existed before. The term *secondary cyclone* means cyclogenesis occurring near, and in relation to, a primary cyclone. Obviously, cyclogenesis applies to both secondary cyclones and new storms formed without relation to any other. A *center jump* is considered to be a special type of cyclogenesis and sometimes is indistinguishable from secondary cyclogenesis occurring near the center of an existing storm. The usual means of differentiation used in this paper is as follows: when the two centers are present, there should be a minimum of 3 mb pressure difference between the old center of low pressure and the col separating new and old centers for the case to be classified as a secondary cyclone. Usually, too, when a new center forms on a warm front it is classified as a secondary regardless of other considerations. In most cases, there will be little difficulty in labeling each case properly. It should be remembered, however, that there appears to be a continuous transition zone between secondaries and center jumps. When it is difficult to tell them apart, the forecast will be similar.

When an injection is first established, and a well developed cyclonic circulation is associated with it, the most immediate problem is to determine if a center jump will occur. This requires a determination of the future course and speed of the cyclone, and is best done by the methods given elsewhere in this paper. At any rate, the 18-hour future position of the low center is predicted.

The 18-hour paths of the primary cyclones in two years of the dependent sample of data have been plotted in Figs. 5, 6, and 7. An increase in the sample would unduly complicate the figures and add little. Figure 5 includes all examples that were associated with cyclogenesis and that had courses less than 61° east of north.

All courses were measured from the meridian over the primary storm at the beginning of the track. In each of these graphs, the point of common reference was the center of injection. Figure 6 is a similar plot of the tracks of cyclones that underwent center jumps. Figure 7 is a plot of storm center tracks taken in a similar fashion for all storms associated with new cyclogenesis but with tracks greater than 60° east from north. Note the almost complete separation obtained between the 18-hour future position of the center jump tracks (Fig. 6) and those storms having similar tracks but with new cyclogenesis associated. The small group of tracks moving southeast at the bottom are practically all on greater courses than the limiting value of 104°.

From the behavior of the cyclone track illustrated in these three figures, a method can be deduced for predicting when a center jump will occur and when new cyclogenesis will take place assuming, of course, that an accurate forecast of the 18-hour future position of cyclone centers can be made. All measurements are made between the initial point and the 18-hour position of the low center.

A study of Fig. 6 leads to the following rule: cyclones that have tracks between 61° and 104° east of north and speeds such that the 18-hour position of the low center is expected to lie within the roughly circular area of this figure, will be accompanied by center jumps and no other form of cyclogenesis.

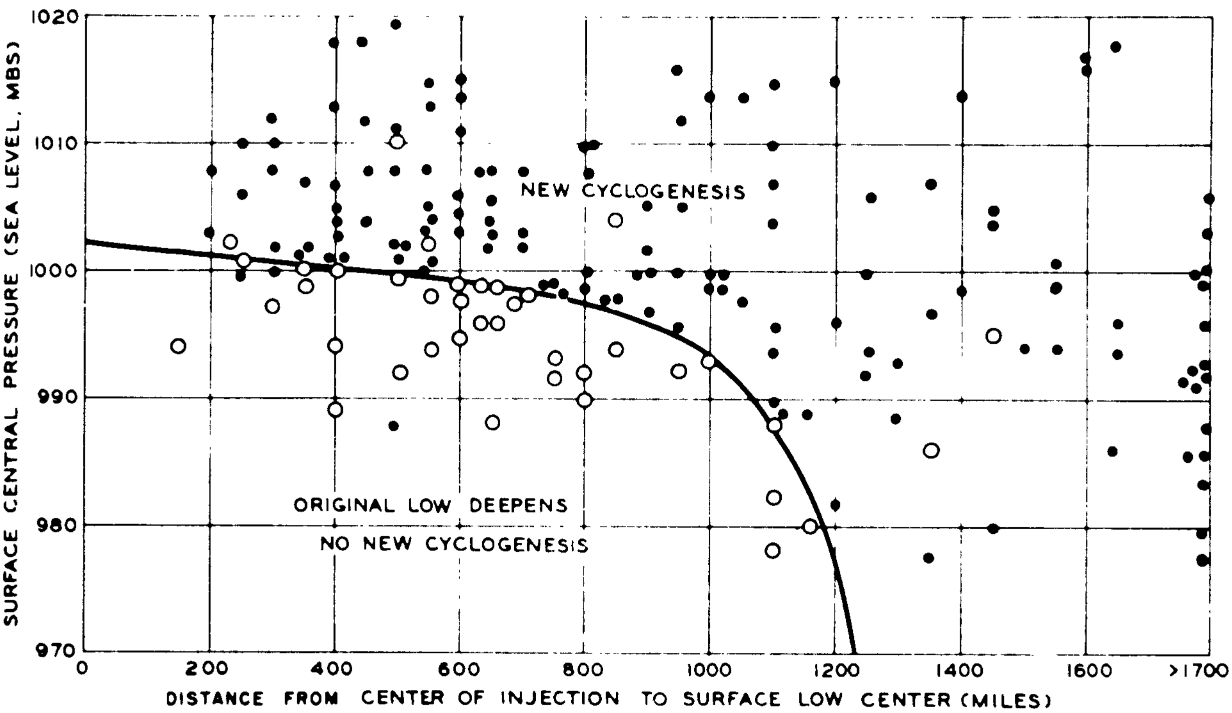


Fig. 8. A method for separating cyclones which deepen from those which are associated with new cyclogenesis. The abscissa represents distances measured in miles between the center of the low at the surface and the center of injection at 850 mb. The low position is taken without correction from the 0130Z or 1330Z chart nearest the time of the 850-mb chart. Ordinates are simply the lowest sea-level pressure recorded for the low. Open circles are shown on the graph for those lows which were not associated with any new cyclogenesis and dots for those which were. The line separates the two classes giving 94 percent accurate definition (dependent data).

In center jump cases, the new center usually moves at approximately the same speed as the old one did before the jump occurred; however, the new center is usually located to the east of the old one. Unless taken into account, this factor causes errors in cyclone speed predictions based on movement of the old center. After a center jump occurs, the intensity of a cyclone almost always increases markedly, and there is a distinct tendency for cyclones of moderate or deep intensity to follow a cyclonically curved track into the north.

The concept of a center jump may appear artificial; however, the need for it was dictated by the data for the following reasons:

(1) There is a real difference in the contour appearance and the resulting weather between a center jump and new cyclogenesis.

(2) A center jump may, and often does, take place so close to the original center that only slight alteration will result in the isobaric pattern. The prediction of location of the new center will frequently be very different than if new cyclogenesis is expected.

(3) We have already noted that following the establishment of an injection either the parent cyclone deepens, a new cyclone is formed, or a center jump occurs. The method for predicting a center jump has just been described. In any single case, once the possibility of a center jump has been eliminated, there remains the very important question of which of the other two alternatives will

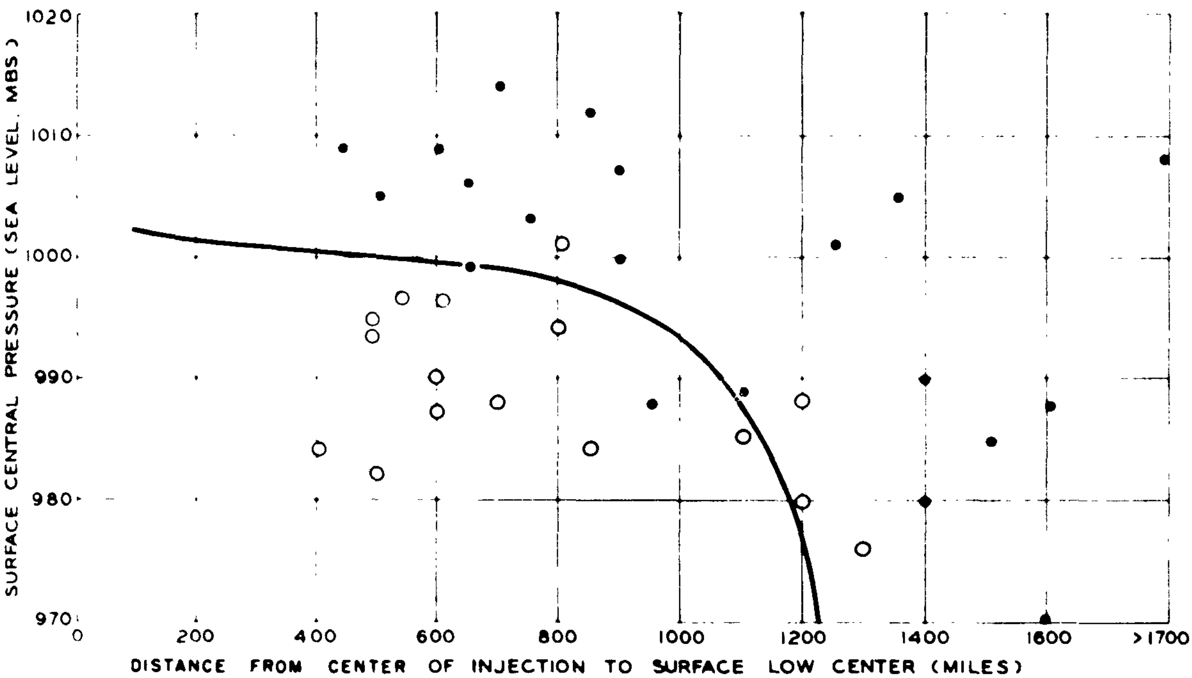


Fig. 9. A test of the deepening or new cyclogenesis separation shown in Fig. 8. The same symbols are used. Accuracy of separation is 85 percent. (Independent data.)

take place. The mechanism by means of which they are separated will be described next. It will suffice here to say that if all center jump cases are not first eliminated, this mechanism is rendered useless.

The tracks of deepening cyclones which are not associated with new cyclogenesis or center jumps are almost always less than 61° east of north and a plot of their tracks as shown in Fig. 5 does not in any way distinguish them from those which are accompanied by new cyclogenesis.

Accordingly, it has been necessary to seek other factors to determine when such a cold air injection will be associated with new cyclogenesis and when it will not. Figure 8 shows that the distance between the parent low and the center of cold injection gives a method of division. When the distance is large, new cyclogenesis occurs. The surface central pressure of the parent low and the distance between the surface low center and the center of cold air injection are plotted as ordinate and abscissa. No center jump cases are included. None of the centers are moving between 61 and 104°. The division is remarkably good giving an over all accuracy for the dependent data of 94 percent. Figure 9 is a similar plot of independent test data using the winter of 1951-52. Accuracy drops to 85 percent which is still satisfactory.

Using independent data it is not easy to find some objective measure of testing these predictions. The winter of 1951-52, comprising 60 cases, was used as an independent check. There are, however, six different components of the forecast (time, intensity, location, speed, track, type) and there were few cases when the forecast was entirely satisfactory for all of them. Of the 60 cases, the essential development was correctly forecast 45 times or 75 percent. There were 10 cases (17 percent) in which major errors were made but in which substantial portions were also correct. Five complete errors resulted (8 percent) two of which were due to incomplete data in Mexico.

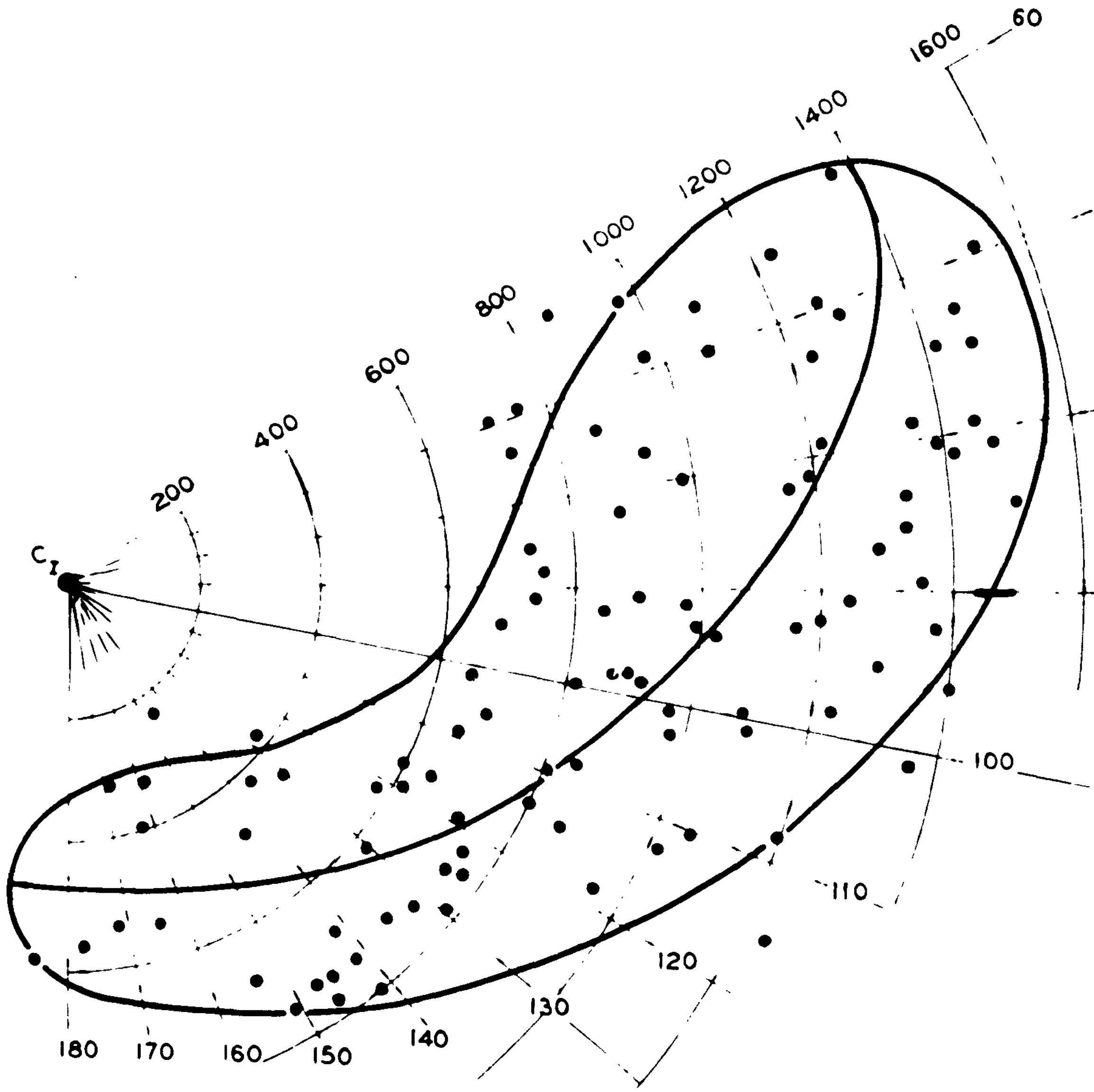


Fig. 10. The location of new cyclogenetic cases referred to a common center of cold air injection. The bearings are determined from the meridian over the center of injection (marked C_I). The distances are scaled in statute miles from a Lambert conformal conic projection with standard parallels at 25° and 48° 30'. Differences in scale due to the projection have been ignored. The polar coordinates have been shown to enable the diagram to be reproduced to any map scale. No center jumps have been included in this sample. They occur mainly north of the 90° line. The preferred location for prediction is usually along the center line. In synoptic practice the area is best transferred in proper scale to a transparency. The center of injection is placed over the actual center and the 90° radian where it crosses the outer line of the kidney-shaped area is placed on the same parallel. The area is then properly aligned and may be traced or indicated on the actual chart.

It must be remembered, however, that if cyclogenesis is correctly forecast as to location, the forecast for 24 to 36 hours is almost certain to be fairly accurate. Any errors in speed, direction, or intensity will only affect the forecast for a later period and presumably later information may permit correction of such errors.

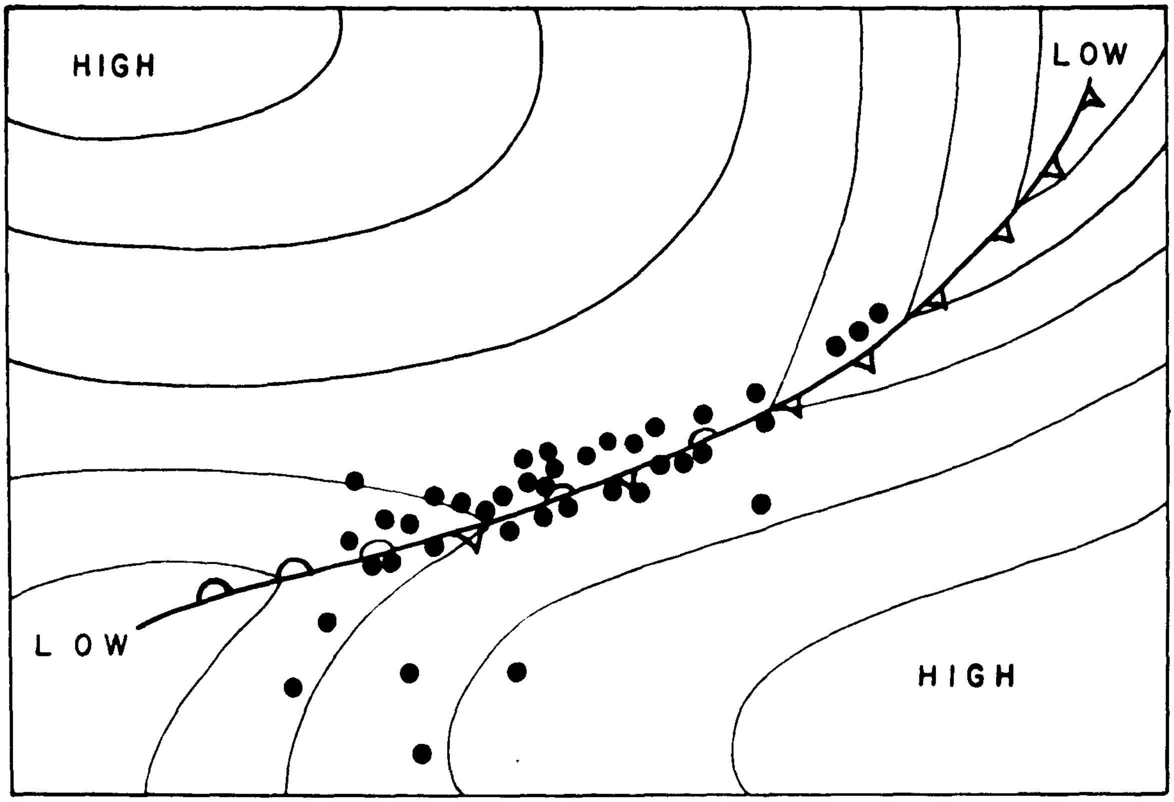


Fig. 11. The synoptic location of new cyclogenesis for the most usual synoptic situation at the time of cyclogenesis. The new cyclone forms in the north portion of the col or even within the northern low when the front is oriented north-south or nearly so. As the front orientation rotates to northeast-northwest, the new depression tends to form in the middle of the col, and as it approaches east-west, it forms most often at the extreme southern and western portions.

It is assumed that the methods developed so far enable the forecaster to determine whether or not cyclogenesis will occur and, if so, the type of cyclogenesis. It now remains to establish methods for forecasting the following information concerning new cyclogenesis: location, timing, intensity of development, track, and speed.

1.3. LOCATION OF NEW CYCLOGENESIS

In Fig. 10 all cases of new cyclogenesis (including center jumps) have been plotted relative to a common center of cold air injection. The kidney-shaped area encompasses most of the locations. It is used as a first approximation for the predicted center by placing a transparency of this figure on the 850 mb chart in proper orientation with the center of injection. The new center will develop within this area. It is usually preferable to predict the cyclogenesis to take place along the center line which will be called the "Locus of Cyclogenesis." Methods described below are useful in placing the location along the extent of this locus.

The location of cyclogenesis in the usual synoptic situation at the time it occurs is shown in Fig. 11. When the front is oriented north-south or nearly so, the new cyclone forms in the north portion of the col or even within the northern low. As the frontal orientation rotates to northeast-southwest the new depression tends to form in the middle of the col and as it approaches east-west, it forms most often at the extreme

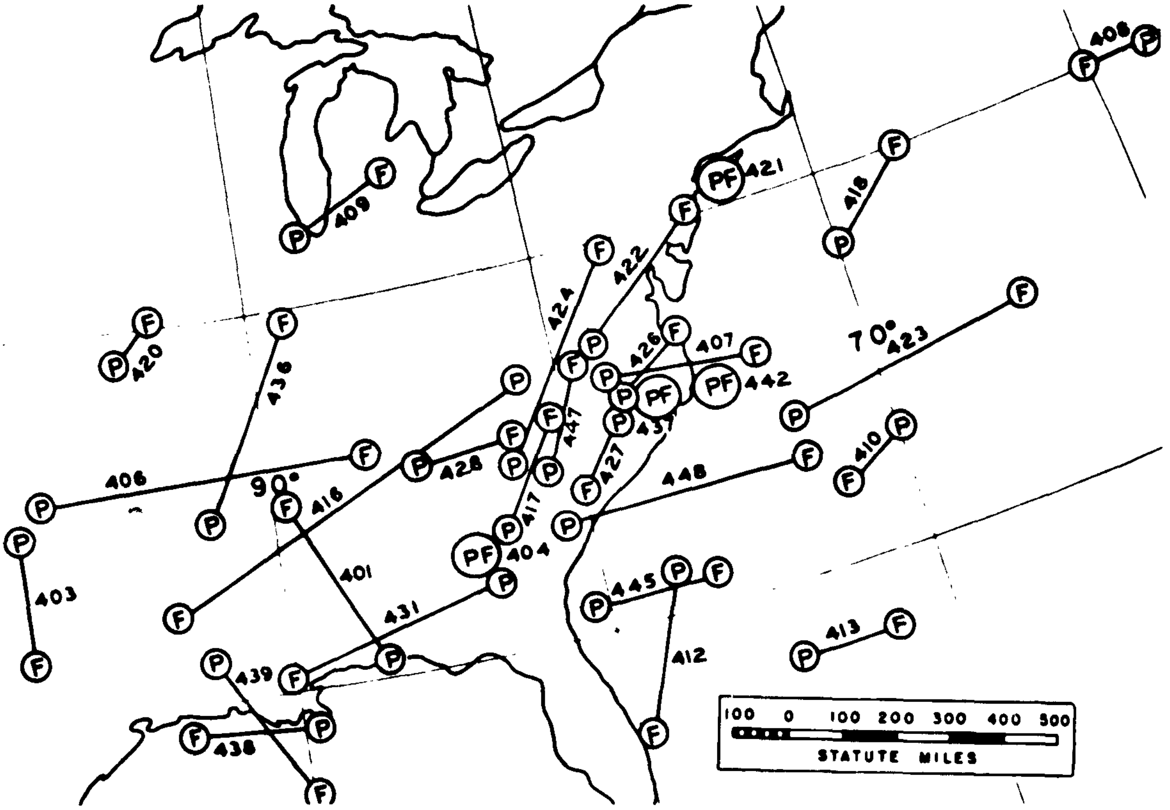


Fig. 12. The predicted and actual locations of cyclogenesis. *P* stands for predicted, *F* for actual position of formation. The numeral refers to the case number in Appendix I. (Independent data.)

southern and western portions. When no parent low is involved, the new storm almost always forms at the extreme south of the locus line.

When the isotherm ribbon is packed closely, i.e., the gradient is high, the point of cyclogenesis is almost always well south along the locus. Conversely, loosely packed isotherms are associated with northerly locations. The gradient value for the median case when cyclogenesis takes place due east of the center of injection is about 15° C per 350 statute miles. As the gradient increases, the predicted position should move southward and as it decreases, northward. This indication is not in conflict with any previously given, for north-south fronts usually are associated with loosely packed isotherms and east-west fronts with high south to north thermal gradients.

Center jumps almost always take place in the northern portion of the kidney-shaped area. Gulf of Mexico depressions which move eastward along the Gulf Coast are exceptions. These nearly always jump across Florida in a northeast direction and may be in the center or in the southern part of the kidney-shaped area.

Another aid in determining the location of cyclogenesis within the kidney-shaped area is the temperature of the 850 mb surface over the locus of cyclogenesis. Table 1 gives the median temperatures and usual ranges. The cyclogenesis most often occurs at the intersection of the locus of cyclogenesis and the median 850 mb isotherm.

Table 1. 850 mb temperatures over the point of cyclogenesis taken at the time of prediction.

	Median 850 mb Temperature	Usual Range
Nov.	10	5 to 15
Dec.	9	5 to 15
Jan.	5	0 to 13
Feb.	8	3 to 13
Mar.	10	7 to 15

There are occasional instances departing widely from these values and they are useful only for checking purposes. Center jumps nearly always occur in parts of the kidney-shaped area where temperatures are much lower than these values (roughly 0° to −20° C).

Figure 12 is a map showing predicted and observed locations of cyclogenesis for the independent data. The reader can obtain from it an idea of the order of accuracy obtainable.

1.4. TIMING

Little can be added to the generalities already given on page 24 concerning the timing mechanism. Eighteen hours is the most common time lag between establishment of an injection and the subsequent cyclogenesis. For injections centered north of 37° latitude, the first appearance of the injection is ignored and an 18-hour time lag is forecast from the second consecutive 12-hour map. This has proved the most satisfactory adjustment for the latitude factor. There are many times when an injection is borderline, for example, when it occurs at a very oblique angle on one map and becomes clear cut on the next. In such cases 6 or 12 hours should be deducted from the usual 18-hour lag from the second map time.

1.5. FUTURE INTENSITY

Throughout the research on this subject, it was found that a correlation existed between the intensity of the cold air injection at 850 mb and the resulting intensity of cyclone development. The initial intensity of the nascent cyclones depends mostly upon the vigor of the 850 mb cold air injection. Shafer, in another section of this paper, found that older cyclones (Category IV) depend upon higher level (500 mb) parameters for deepening especially when the cyclone is weak. However, he found that for strong cyclones of this category, further deepening was best indicated at 850 mb.

Figure 13 shows the relationship between the intensity of the cold air injection and the initial cyclone intensities using the count system described in the introduction. The results from this graph can usually be improved upon by a subjective correction according to whether the 500 mb surface is favorable for further development.

Figure 14 is a graph similar to Fig. 10; however, the intensities plotted are the maximum attained during the 30 hours following the birth of the cyclone and the family of curves is naturally displaced a little. It is the first phase of a multiple correlation designed to give future intensity. Figure 15 is the second phase which takes into account the trough sharpness and temperature gradient at the 500 mb level.

Figure 16 is the final graph plotting the 500 mb results as abscissa and the 850 mb parameters as ordinates. Major storms are defined as those which reach an intensity count of 16 or more. Minor storms have

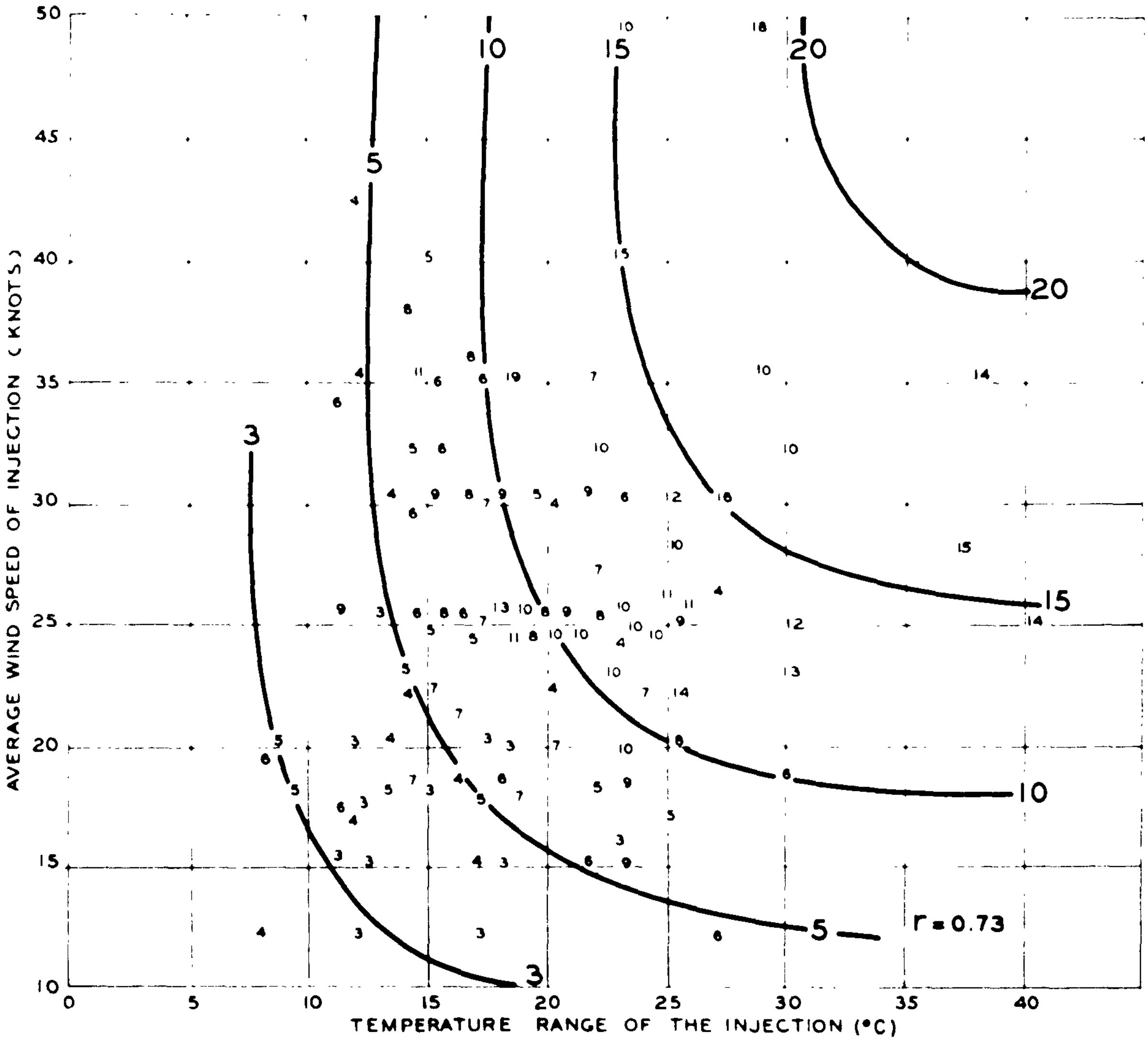


Fig. 13. The initial intensity of new cyclone formation determined by the first plateau of intensity values after the new cyclone forms. If a continual increase in intensity is noted, the first measurable intensity is chosen. The abscissa represents the temperature range of the optimum streamline through the isotherm ribbon. The ordinate values are the average wind speed along the optimum streamline weighted by eye according to the intensity of thermal gradient in each section. The family of curves is labeled in intensity scale values for the initial strength of the new cyclone.

counts of less than 16 but usually from 8 to 15. Fillers, of course, disappear. Frequency of distribution of the three storm classes is indicated in the appropriate areas and the graph is obviously a valuable forecasting tool. All data for this graph were taken from the prediction charts approximately 18 hours prior to the appearance of the first closed isobar.

1.6. THE FUTURE TRACK

The initial estimate of the track of the resulting storms is chosen as the mean between the steepest portion of the eastern troughs of isotherms and height contours just east of the cold air injection at the time

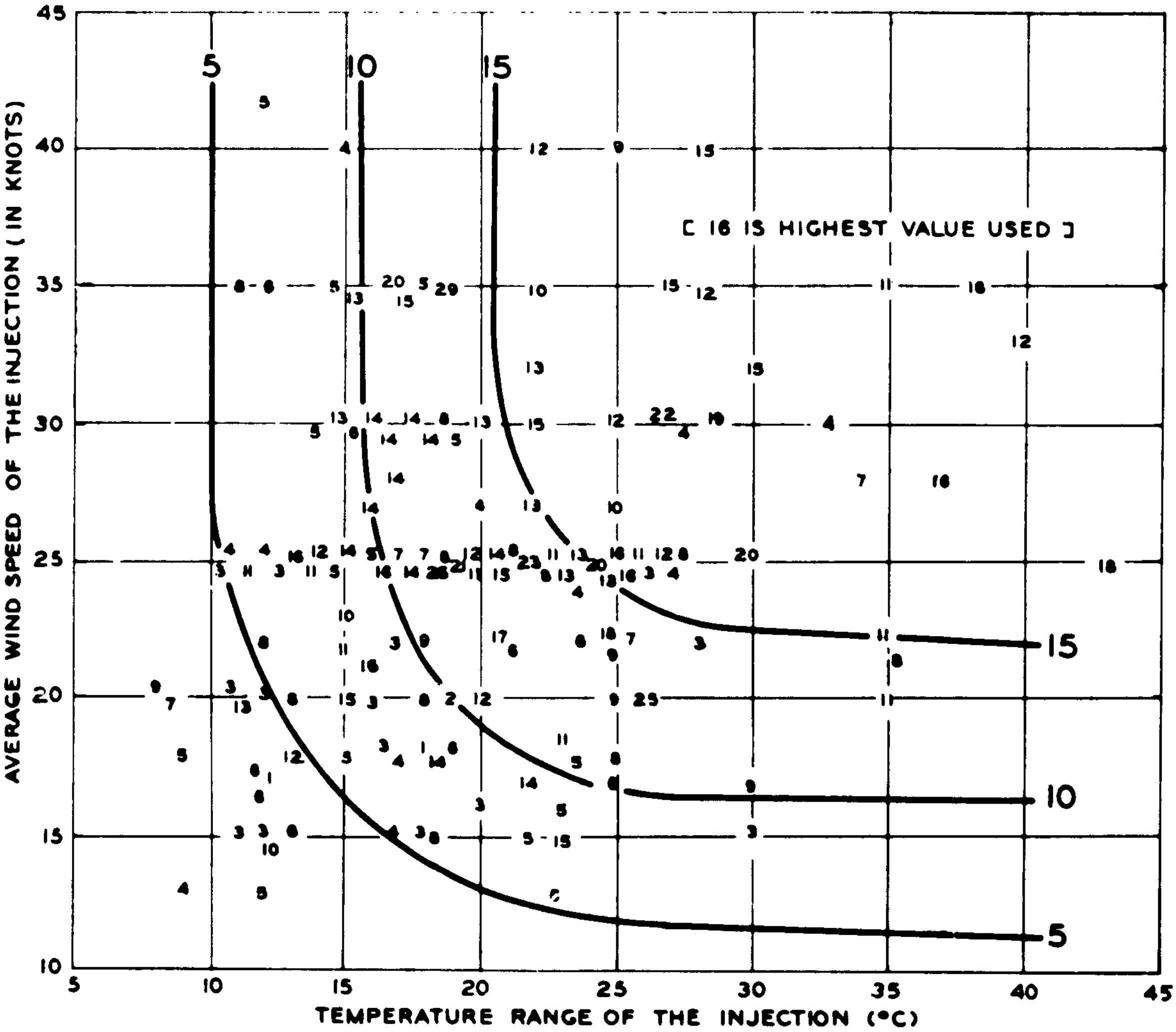


Fig. 14. The first stage of a multiple correlation technique for forecasting the maximum intensity in new cyclogenetic cases. The figures entered are the maximum intensities of the new cyclone in the first 36 hours of its existence (54 hours from forecast time). The temperature range and average wind speed were described in the legend for Fig. 13.

when prediction can be made (P-Hour). Figure 3 contains an illustration of how these are chosen. This direction is then corrected in accordance with the relationship expressed in Fig. 17. There are occasional large departures from forecast values of this element. When the amplitude of the isotherms is less than 10° of latitude through the center of cold injection, the new cyclone will usually curve to a course of west to east within 24 hours even if its initial course is nearly northerly.

1.7. THE PREDICTED SPEED

The speed of the new cyclone is related to the 850-mb thermal gradient to its northwest and to a representative 850-mb wind speed in the area between C_i and the location of cyclogenesis. Figure 18 expresses this relationship numerically. The results of a test of the independent data sample for both initial track and

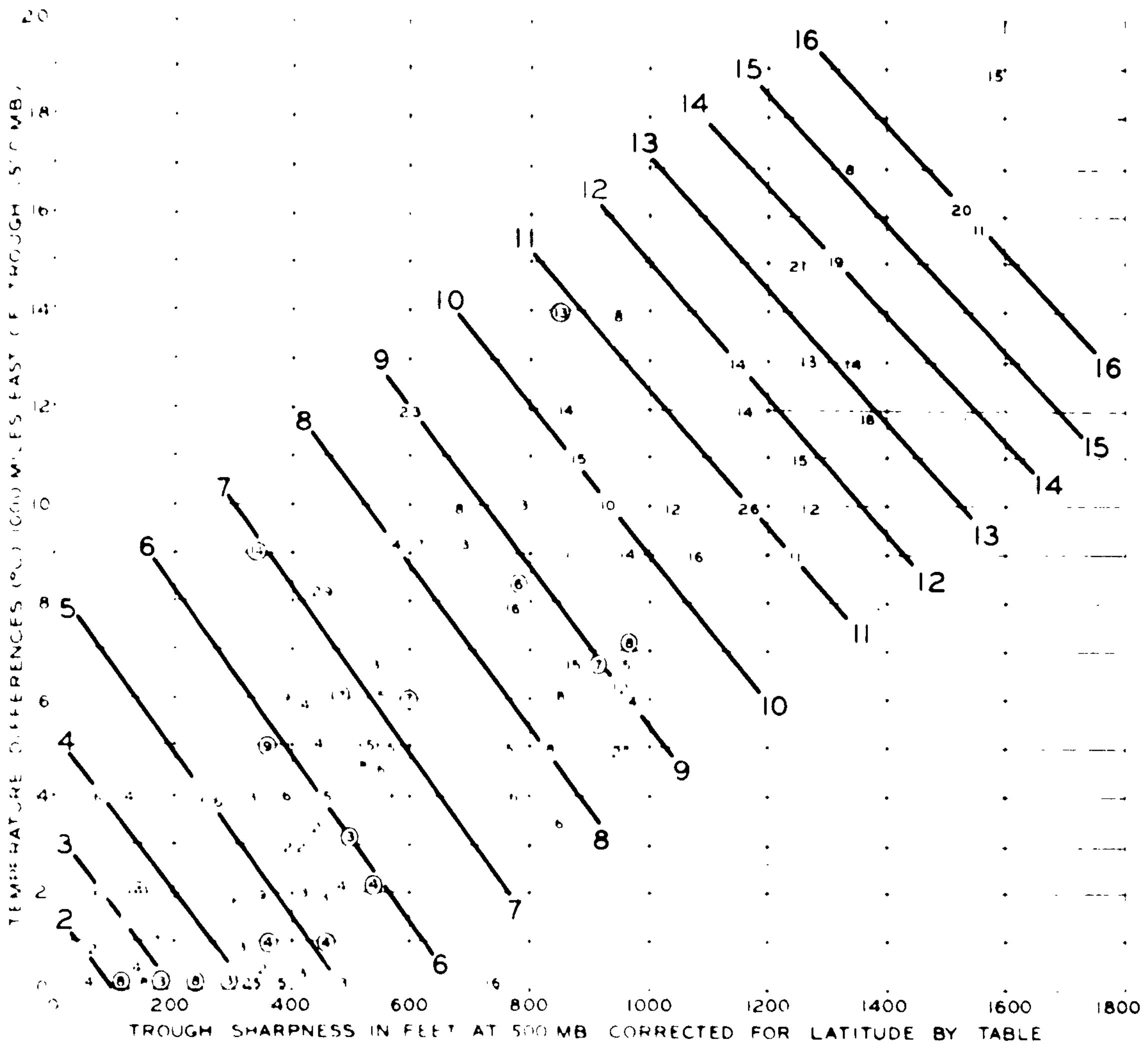


Fig. 15 The second stage of a multiple correlation technique for forecasting the maximum intensity of new cyclones. These parameters are both obtained from the 500-mb chart at the time the prediction is made. The figures plotted are again the maximum intensity of the resulting cyclone. The circled figures refer to filling storms. The trough sharpness is the same parameter used in Category IV for determining deepening, i.e., the height difference in feet between the trough line and a point 1000 miles east, plus the same measurement 1000 miles west, all taken at the latitude of predicted cyclogenesis. When the trough is more than 1000 miles from the predicted cyclogenesis, it is carried to the final correlation graph (Fig. 16 as zero) unless its extrapolated movement brings its predicted location within the 1000-mile range within 24 hours after the time of prediction. The full value of the parameter is then used. In some cases the subsequent sharpening or flattening of troughs is apparent and may be allowed some subjective weight.

The temperature differences between the trough line at the latitude of predicted cyclogenesis and a point 1000 statute miles eastward are used as ordinates. The differences are considered positive when the warmer air is at the eastern point. Negative differences are shown as zero on the figure.

speed are given in Tables 2 and 3. It is obvious from these results that the large variations from forecast values will be encountered not infrequently. This is hardly surprising considering that the forecast is made some 18 hours before the cyclone is even in existence and the situation contains inherently large values of acceleration. Nevertheless, these forecasting relationships still contain valuable information and are superior to any subjective method presently available.

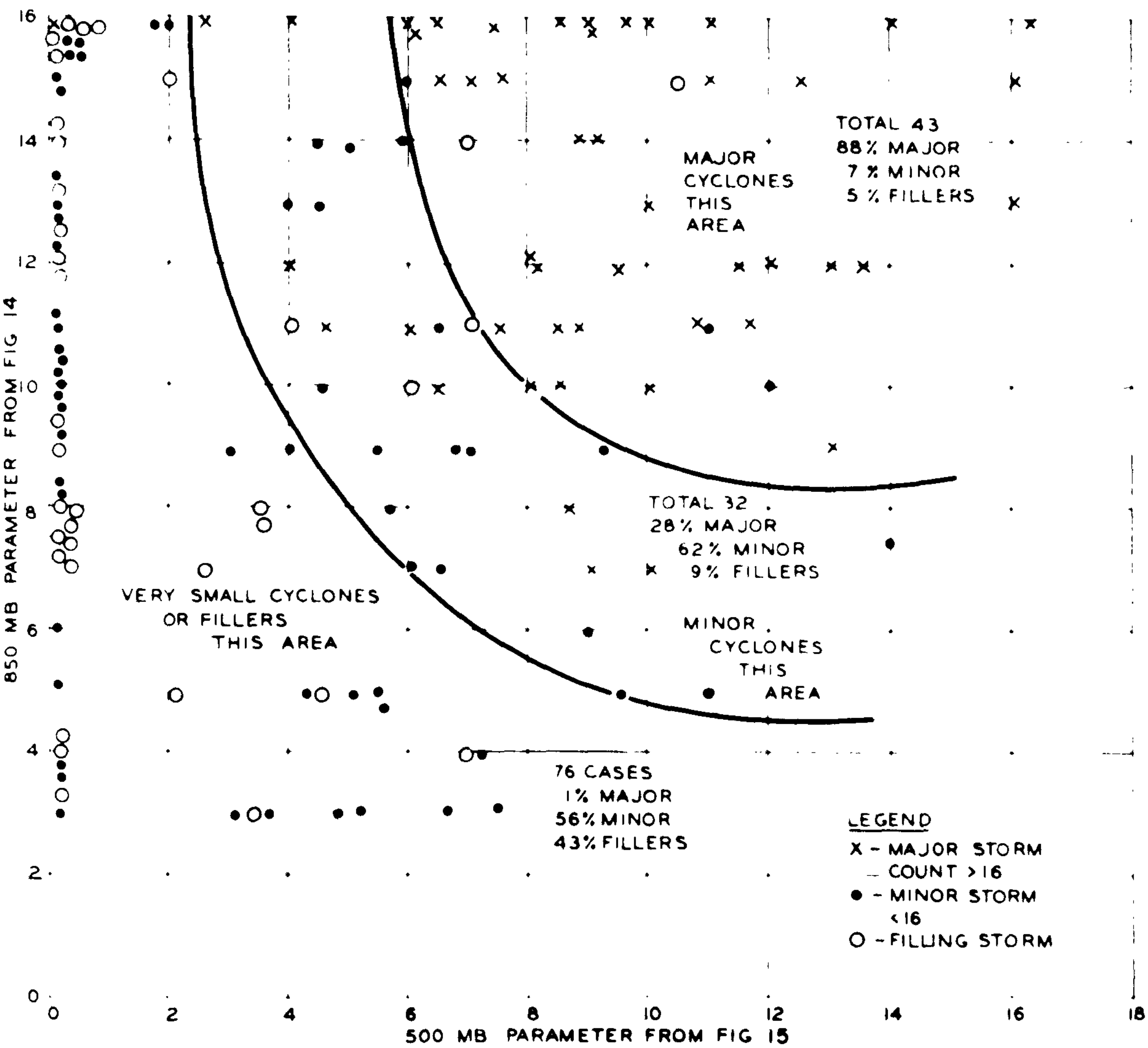


Fig. 16. The final correlation for predicting maximum intensity of the new cyclone. The ordinate represents the values obtained from the preliminary graph of Fig. 14 and the abscissa represents those obtained from Fig. 15. The three areas are plainly delineated and the suggested forecast for each area is noted therein.

1.8. EXCEPTIONS

1.81. *Special Category Cyclones*

Special category cyclones (defined in the section on Category IV cyclones) are always intense, slow movers. Frequently, at one stage in their history, they move in a direction west of north. Normal forecasting methods are not used with these storms; instead, the following rules are utilized. A center jump almost invariably occurs and should always be forecast approximately due east of the original center and

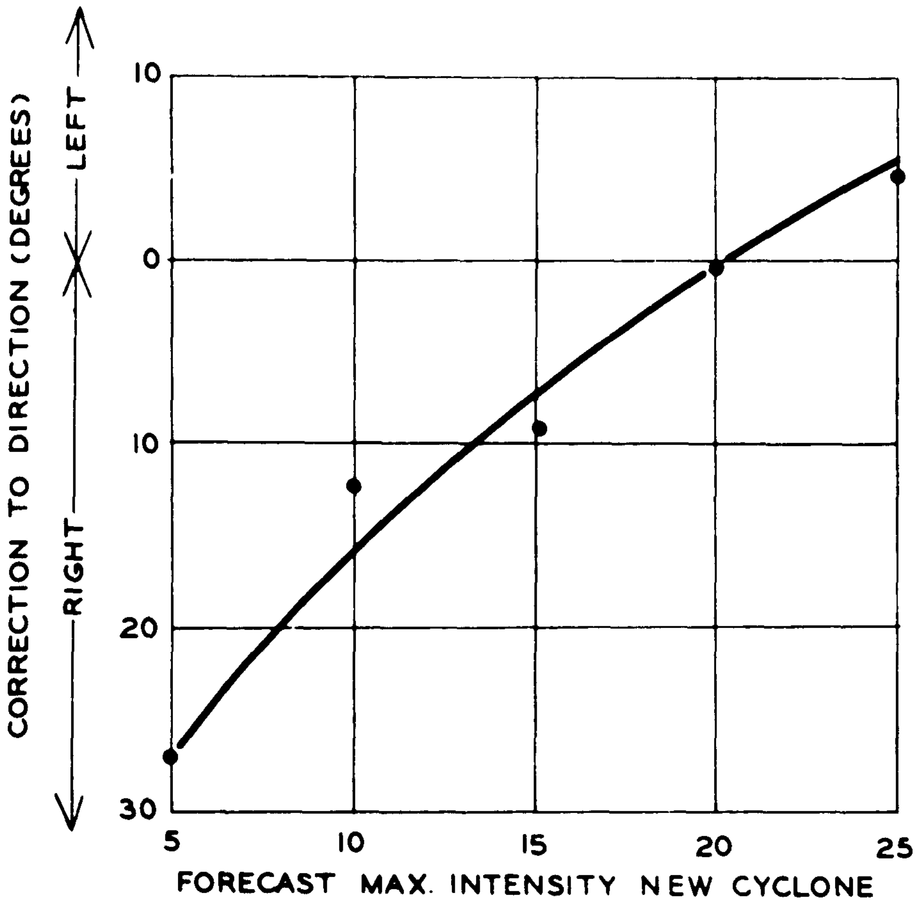


Fig. 17. A correction to be applied to the initial direction as determined from the orientations of contours and isotherms. The abscissa is intensity of the new cyclone determined from Fig. 16 as follows: the curve separating "fillers" from minor cyclones represents a value of 8, the curve separating minor cyclones from major cyclones represents a value of 16, and variation of intensity normal to these curves is assumed to be linear. The ordinate is the desired correction.

roughly 500 miles from it. In most cases it takes place later than the observer would be led to believe. Generally, a secondary storm formation follows closely to the southeast of the center jump position, and this storm usually develops and becomes the dominant map feature.

1.82. *Cold Tongues*

Occasionally, a carefully drawn upper air chart will reveal a tongue of cold air, curved cyclonically and usually with a current of air of jet stream configuration having an axis near the cold air axis. Such occurrences may be found at any level, but need be present at only one. When encountered, such cold tongues require all normal forecasting methods to be ignored. A deep cyclone is forecast 18 hours later for a point about 1000 miles downstream along the axis of the cold tongue which is extended in a smooth curve and about 200 miles north of the curve. Care must be taken to require a real cold tongue before making this forecast for there are many occasions when isotherms assume an S shape without having the required narrow tongue characteristics. Sometimes new cyclones form at the point mentioned and at times already existing

Table 2. Predicted initial tracks and speeds of new cyclones made 18 hours before the cyclone forms (independent data).

Case No.	Average Direction Isotherms and Contours	Correction for Intensity	Forecast (Degrees from North)	Actual (Degrees from North)	Forecast Speed (mph)	Actual (mph)
401	65	−5	60	45	–	45
403	85	0	85	70	32	32
404	3	+7	10	35	42	56
406	75	+7	82	74	32	55
407	40	+7	47	38	43	65
408	39	+7	46	31	33	27
409	23	+18	40	55	43	64
412	75	+27	102	–	20	10
413	70	−5	65	50	20	28
414	20	0	20	78	34	37
415	22	+27	49	55	30	20
416	29	+10	39	40	20	65
417	60	+27	87	95	20	24
418	68	+7	75	64	33	31
420	65	0	65	75	32	40
421	69	−5	64	53	38	42
422	66	0	66	57	40	33
424	79	+15	94	80	20	48
425	46	+7	53	57	20	40
426	47	0	47	46	20	32
427	70	−5	65	72	37	35
428	42	−5	37	72	37	35
431	58	−5	53	45	48	60
434	42	+15	57	60	21	23
436	40	+7	47	90	38	20
437	35	0	35	74	29	29
438	55	+15	70	90	26	60
439	90	0	90	78	20	30
442	45	+7	52	350	38	15
445	82	+10	92	70	38	23
446	15	+15	30	90	20	25

Table 3. Recapitulation of Table 2.
(Percent of Occurrences)

Error	Less than 11	11–20	Over 20
Initial Track	40	30	30
Speed	55	20	25
Both Within Limits	27	23	50*

*Either speed or direction missed more than 20 (degrees for direction, mph for speed).

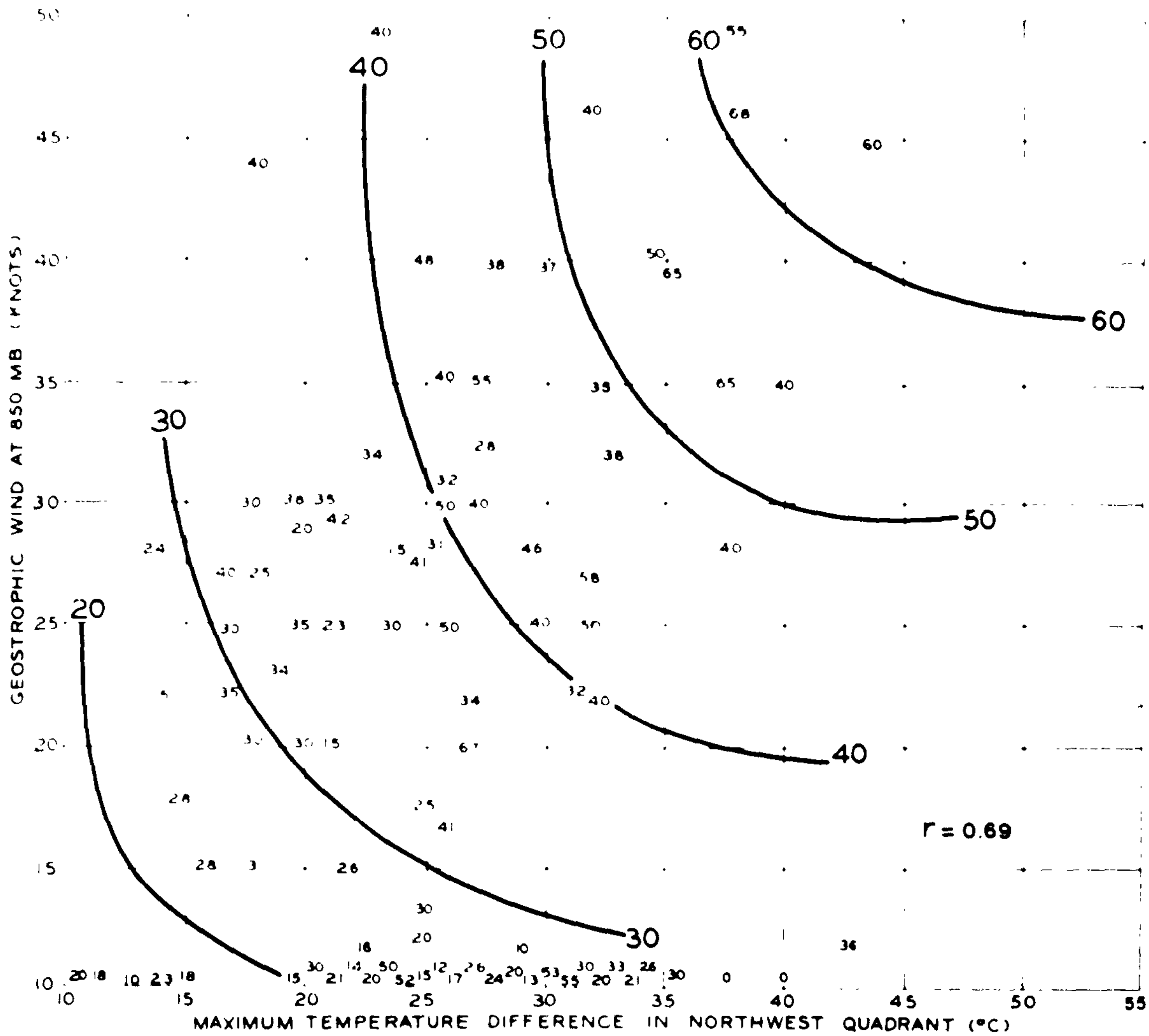


Fig. 18. A method for estimating the speed of the new cyclone. The geostrophic wind at a representative point in the southwest flow between the center of injection and the predicted position of cyclogenesis is plotted as the ordinate. The points of the abscissa represent the temperature difference measured between the position on the locus of the cyclogenesis line within 200 or 300 miles of the predicted position of the new storm which will give the maximum temperature difference to a point 1000 miles in the northwest quadrant. This measure is flexible since occasionally small differences in choosing the position of predicted cyclogenesis (which frequently occur) may make large differences in this temperature difference. All measurements are taken at 850 mb. When the geostrophic wind measures 10 mph or less or when the southernmost contour around the 850-mb trough lies north of the predicted position of cyclogenesis, a speed of 20 mph is predicted arbitrarily.

EXPLANATION OF SYMBOLS FOR FIGS. 19 THROUGH 31.

L 998 — PRIMARY LOW CENTRAL PRESSURE 998 MB.

P-HOUR — HOUR AT WHICH PREDICTION CAN BE MADE.

P+15 — 15 HOURS AFTER TIME OF PREDICTION.

S — CENTER OF SECONDARY CYCLONE.

— SYMBOL INDICATING A COLD AIR INJECTION.

● — CENTER OF COLD AIR INJECTION.

— DIRECTION CHOSEN FOR STEERING FROM ISOTHERMS.

— DIRECTION CHOSEN FOR STEERING FROM CONTOURS.

ΔT — THE DIFFERENCE IN TEMPERATURE AT 850 MB MEASURED TOWARD COLD AIR FROM THE PREDICTED POINT OF FORMATION OF THE NEW CYCLONE AND OVER A DISTANCE OF 1000 MILES.

-------- — ISOTHERMS (5° C INTERVALS).

———— — CONTOURS (200 FT. INTERVALS).

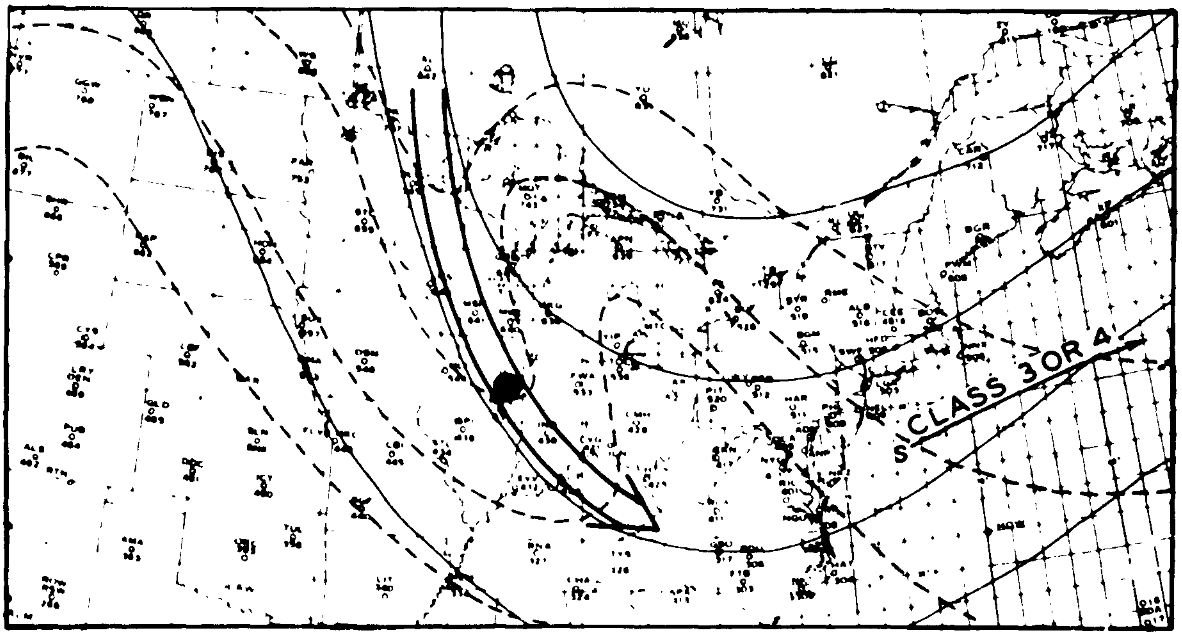


Fig. 19. A form of upper air pattern associated with cyclogenesis even in the absence of any cold air injection at 850 mb. A pattern such as this probably insures strong cyclogenesis. It may be present at any level up to 500 mb, but need be present at only one of them. It was fairly rare, occurring only about six times in the four years examined; but in every case it was associated with a strong cyclone. It is important not to confuse this pattern with an ordinary S shape to the isotherms which are handled in the ordinary fashion. A distinct narrow tongue of cold air moving at high speed is necessary.

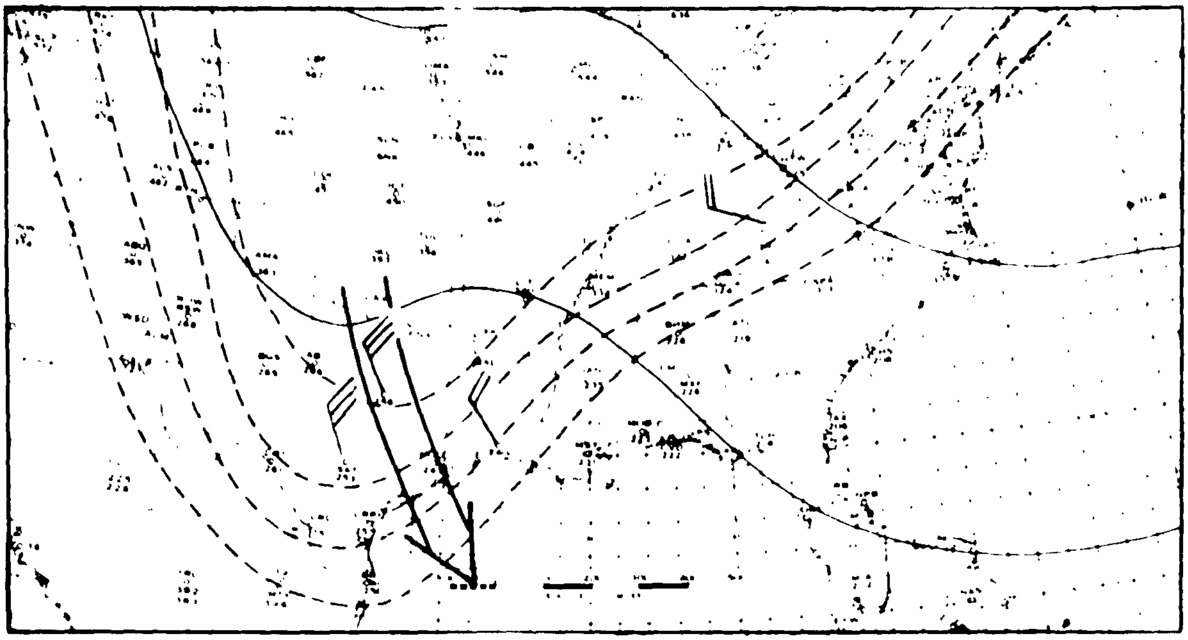


Fig. 20. A negative pattern at the 850-mb level. Although a strong cold air injection is present over Texas, no cyclogenesis occurs when the flow is such as to cause the principal trough in the vicinity of the injection to be a simple perturbation in a broad northwest current.

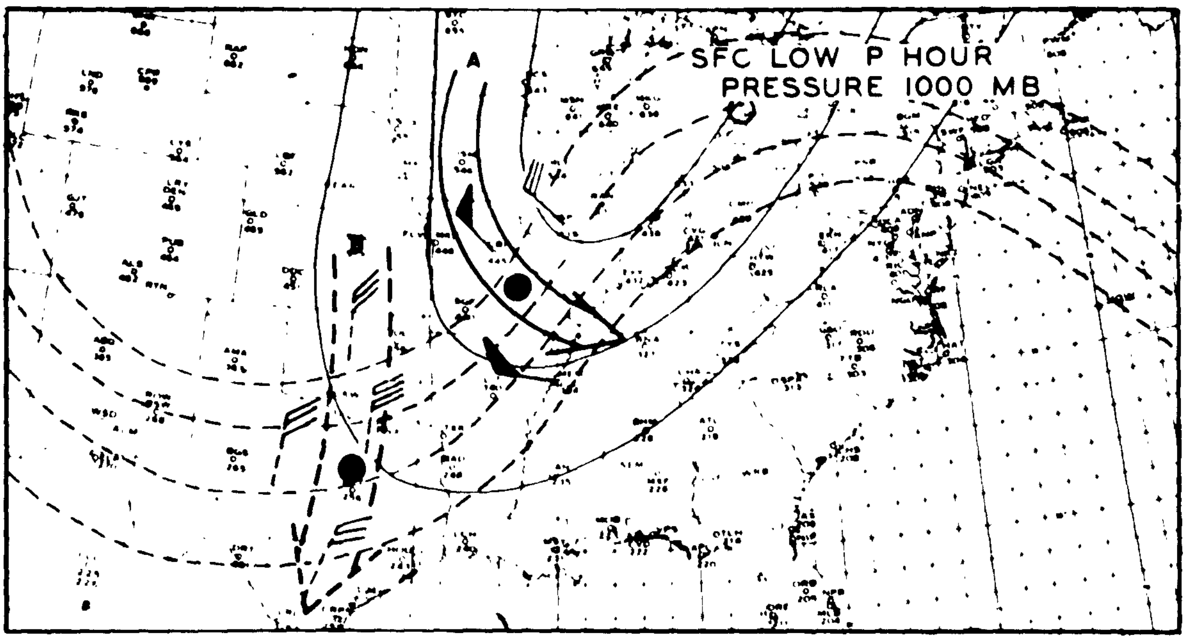


Fig. 21. A frequent pattern showing a double injection. This occurs usually with deep cyclones which move off taking with them a cyclonic injection close to the center but gradually leaving beh'nd a straight line or even an anti-cyclonically curved one. The distance between the center of the storm and the southernmost center of injection should be used to determine if new cyclogenesis will occur. This sort of double occurrence also sometimes happens when two maxima of wind speeds are separated by distinctly lower values.

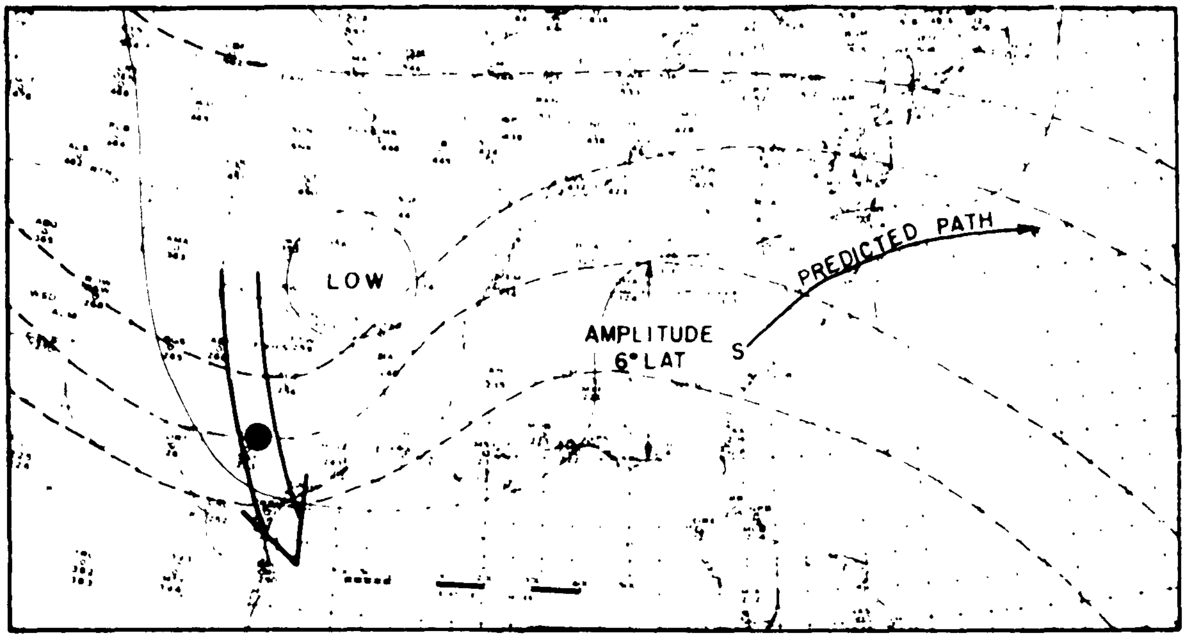


Fig. 22. 850-mb appearance of a slow moving typical storm which recurves to the east within the first 24 hours of its existence. The weak thermal gradient to the northwest combined with the weak wind field promise the slow moving feature while the slight amplitude of the isotherms points to the curving path.

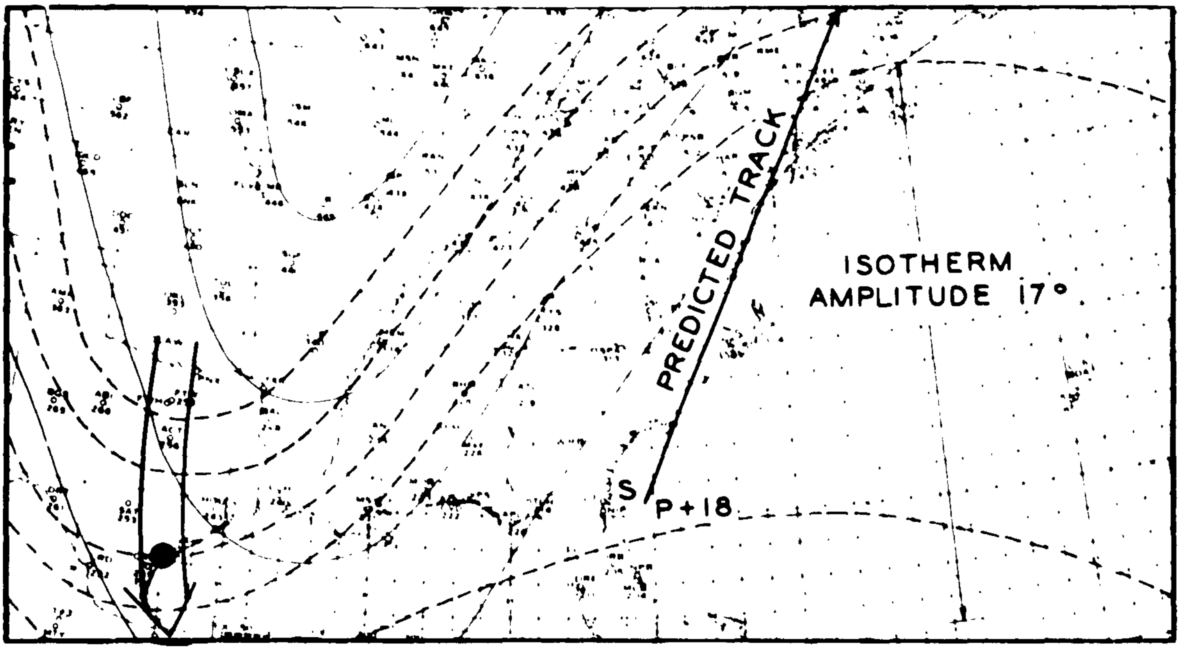


Fig. 23. 850-mb chart appearance of a fast moving storm which does not recurve to the east within 24 hours of its inception. Note the isotherm amplitude is large (17°) which indicates non-curvature and the good gradients of wind and temperature to the northwest and west of the predicted position of formation.

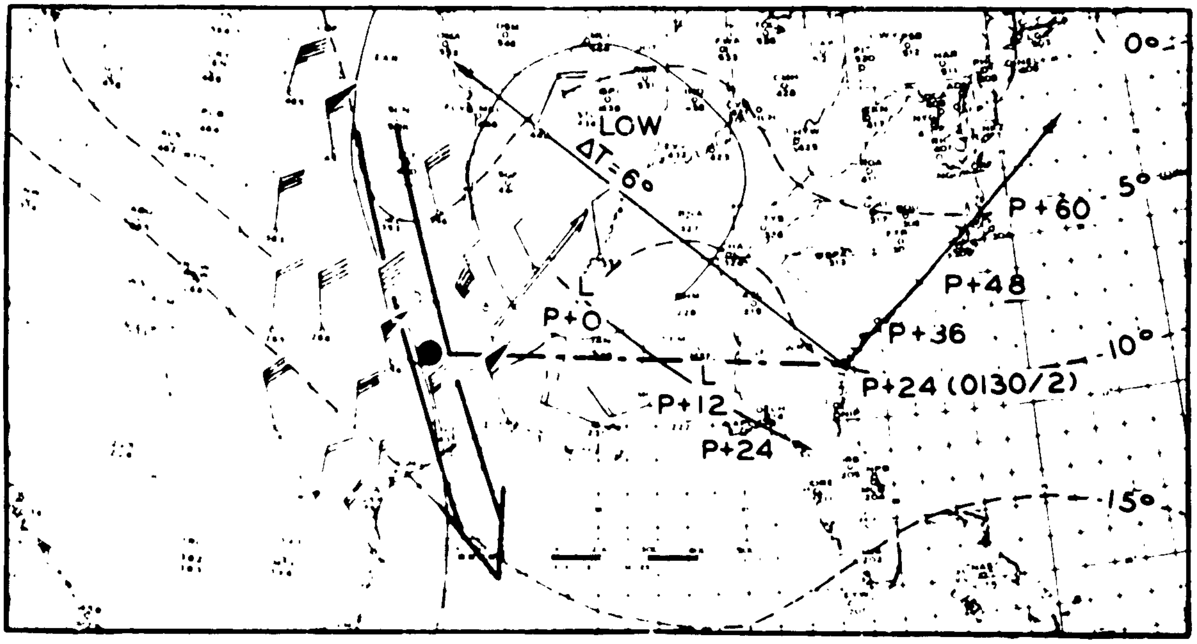


Fig. 24. Actual example. 850 mb chart for 2200E, 31 October 1947. An example of cyclogenesis near Savannah, Georgia, 24 hours after the pattern was established. In this instance curvature to the east would have been forecast, so the predicted location at $P + 60$ near Hatteras would have been in error.

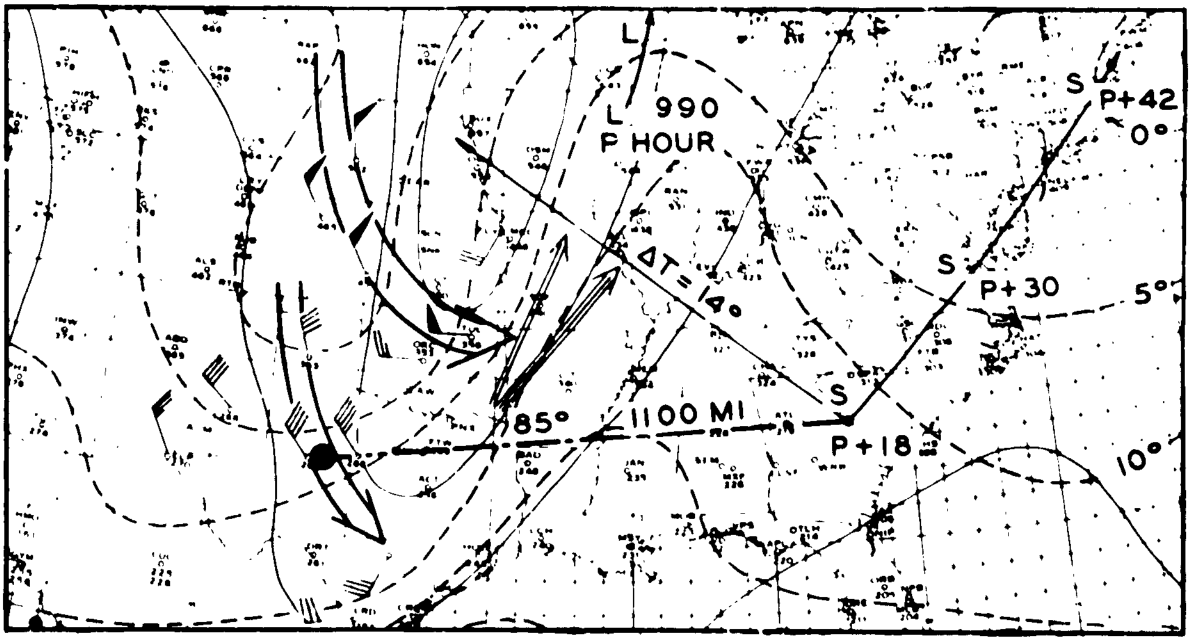


Fig. 25. Actual example. 850-mb chart for 2200E, 6 November 1947. Although the primary low in Wisconsin is deep (990 mb), the distance to the Texas injection causes a prediction of cyclogenesis which actually occurred near Augusta, Georgia, and became a fast moving, strong cyclone starting 18 hours after this map.

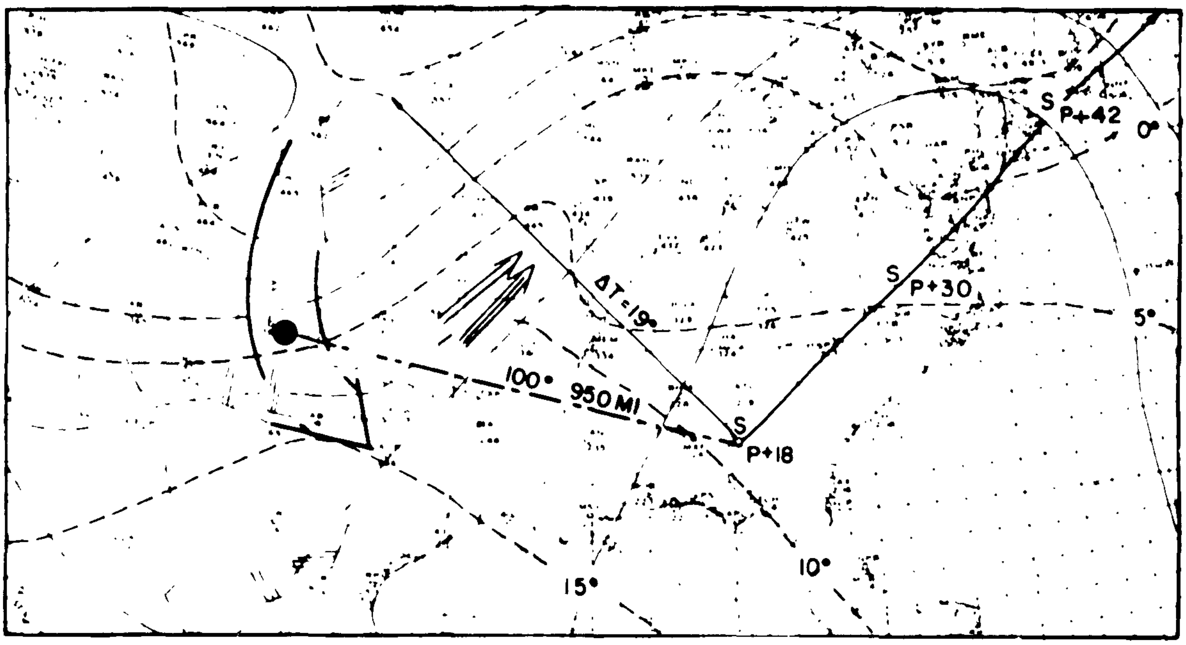


Fig. 26. Actual example. 850-mb for chart 1000E, 10 November 1947. A strong cyclone, fast moving, is formed in Georgia 18 hours after the cold air injection is apparent in Texas. Note that it formed slightly south of the latitude of the injection, and might have been predicted even farther southwest due to no parent cyclone.

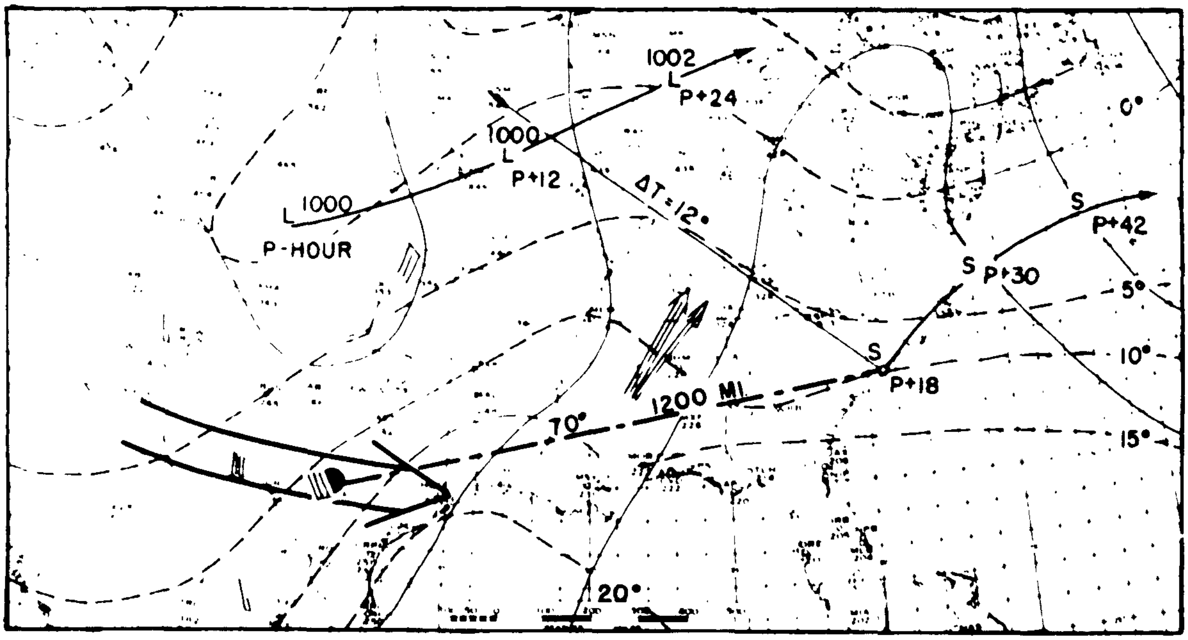


Fig. 27. Actual example. 850-mb chart for 1000E, 14 November 1947. A weak low is formed near Charleston, South Carolina, 18 hours after the Texas injection pattern. Note the curving path, the low amplitude of the isotherms, and the northerly location of the new storm with respect to the center of injection.

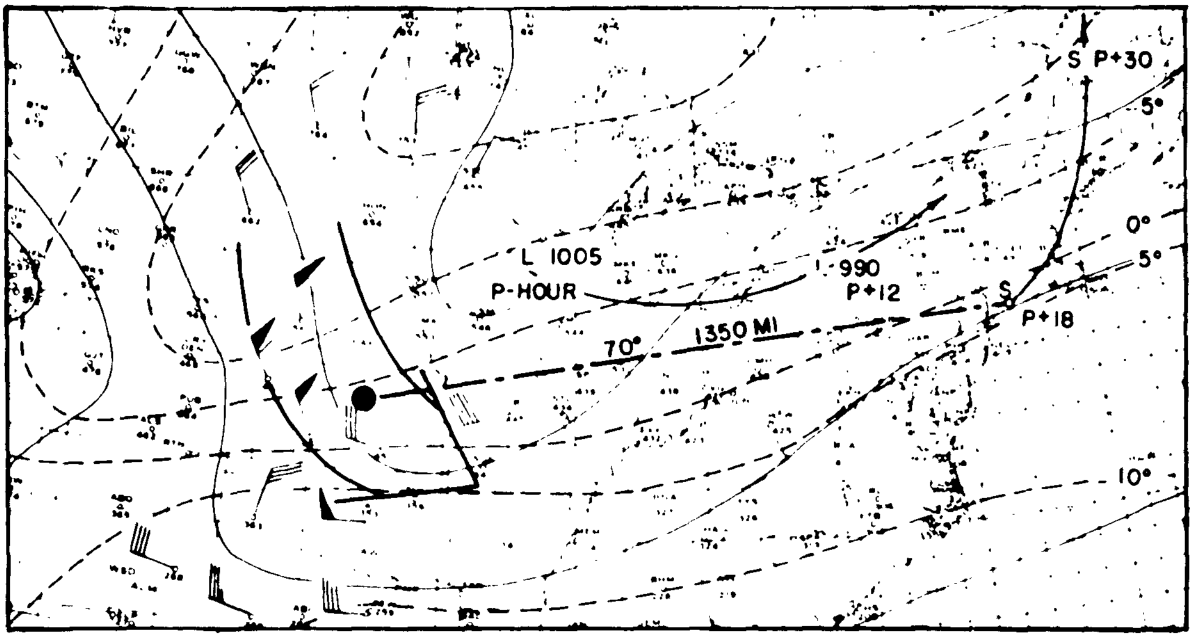


Fig. 28. Actual example. 850-mb chart for 2200E, 23 November 1947. A center jump case. A primary cyclone, central pressure of 1005 mb is only 450 miles from center of injection. Note the easterly course of the primary cyclone which is a requirement for the center jump. Timing is about the same on center jump cases as for new cyclogenesis and the action usually takes place well north of the latitude of the injection.

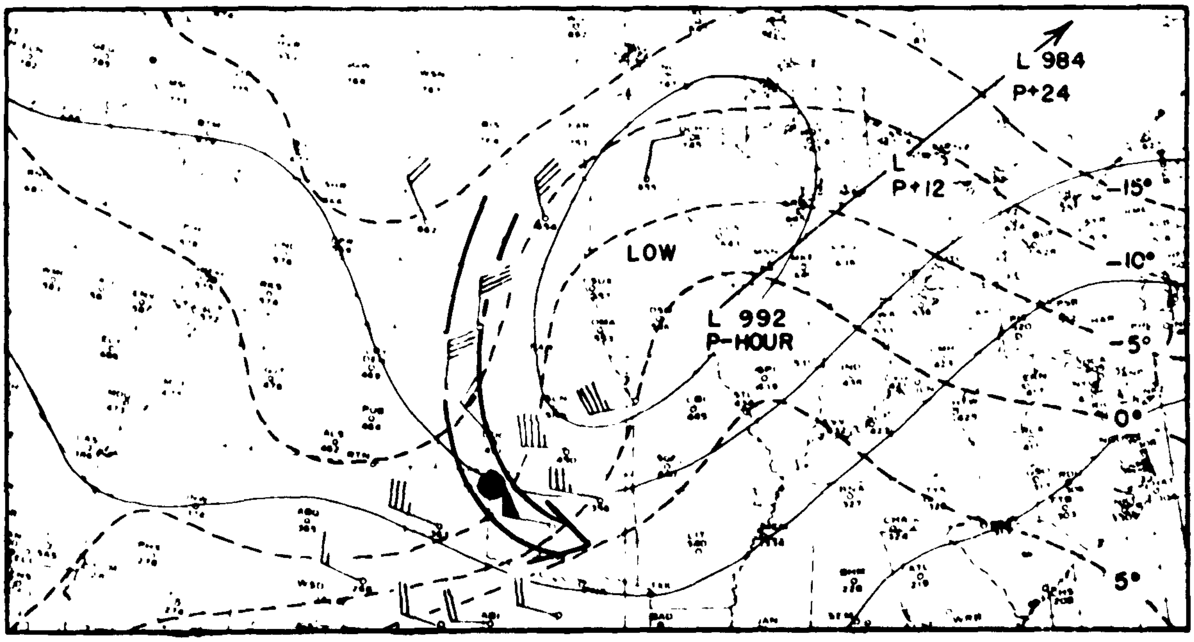


Fig. 29. Actual example. 850-mb chart for 1000E, 7 December 1947. A negative case. The injection while of excellent definition is only 560 miles from the center of the surface low center which has a central pressure of 992 mb. No cyclogenesis would be predicted except for deepening of the primary low and that is what occurred. Such cases usually leave a temporary weak bar metric depression with no bad weather associated to the southwest of the center of injection but in this paper these have not been termed cyclones.

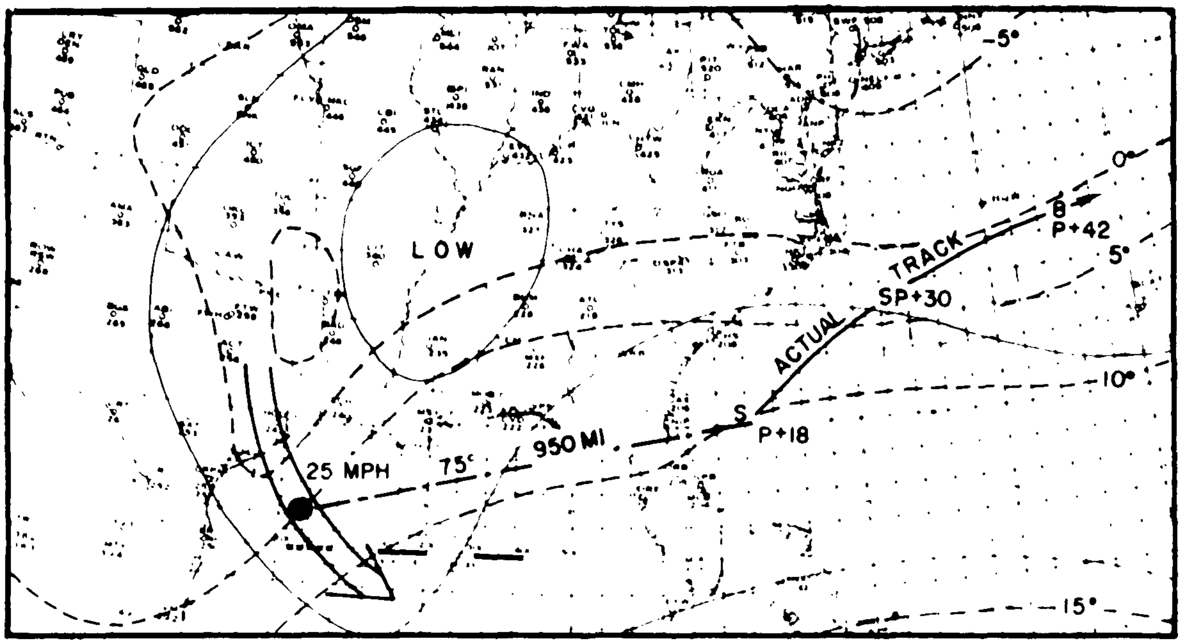


Fig. 30. Actual example of the prediction factors concerned with the famous storm of 26 December 1947 which was supposed to have caused 26 inches of snow to fall on New York City within a space of a few hours. This is a portion of the 850-mb map for 1000E, 24 December 1947, and using the methods described a forecast of a new cyclone (there was no primary) would have been made closely in accordance with the actual track, speed, and intensity which is shown here. Due to curvature to the east, no precipitation or effect on New York would have been forecast at this time. For the conditions preceding the actual storm which caused the snowfall, see Fig. 31.

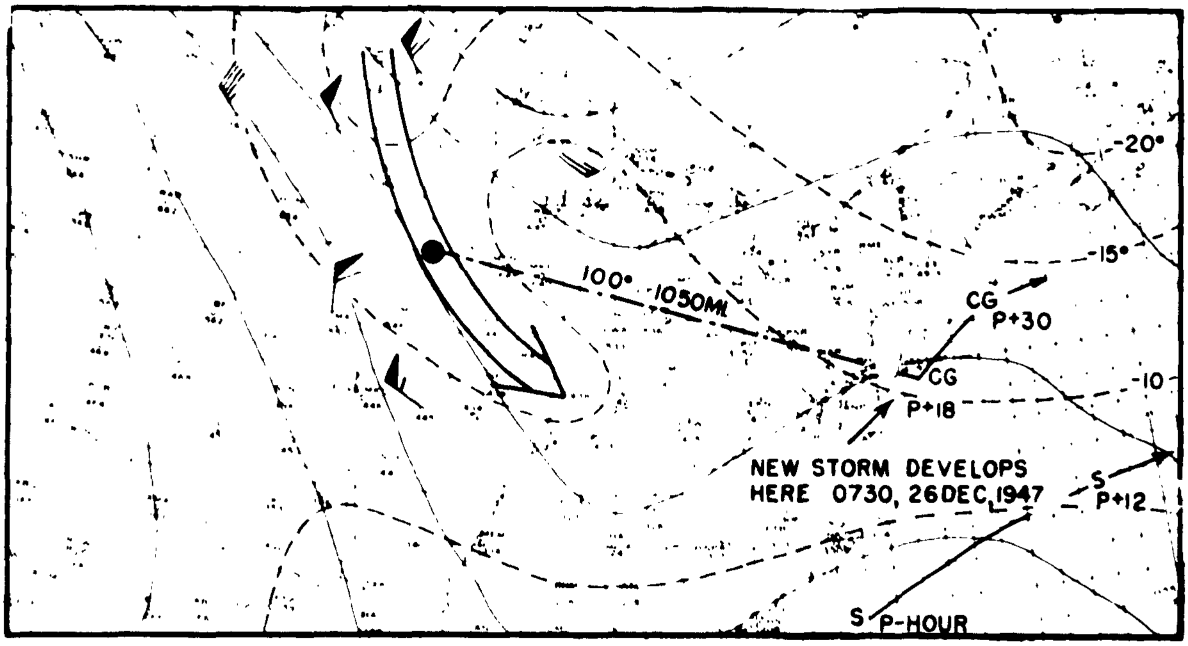


Fig. 31. A section of the 700-mb chart for 1000E, 25 December 1947. The cold tongue type of injection is clearly visible. No injection was discernible at 850 mb but a similar cold tongue was apparent at 500 mb. Many analyses showed the small storm discussed in Fig. 30 moving northwest and causing the snow at New York, but a careful check clearly shows that it actually followed the path indicated, while an entirely new storm formed offshore as indicated to cause the New York snow. Prediction was possible from this chart.

storms move to the required position, but in every case encountered in this investigation one or the other has occurred. However these cases are rare. Figure 19 is an example of this type of synoptic situation.

1.83. *Very Low Level Injections*

There were a number of occasions during this study when minor depressions formed, particularly along the east coast of the United States, and persisted for a day or two without any injection being discernible at the 850 mb level or above. In practically all of these cases, an examination of winds at 2000 or 3000 feet disclosed a distinct cold air injection (using the isotherms at 850 mb) taking place at levels below the 850 mb level. Accordingly, it is necessary to be alert to this possibility if the optimum forecast efficiency is required.

These storms never amount to more than minor depressions but despite, or perhaps because of, their weak pressure gradients, they frequently cause the most widespread and poorest flying weather of any class of storms. They constitute less than 5 percent of all cyclogenetic cases.

1.84. *Negative Patterns*

An injection is not followed by cyclogenesis when the flow pattern is part of a general northwest flow to the east of the injection. Figure 20 illustrates such a case.

1.9. EXAMPLES

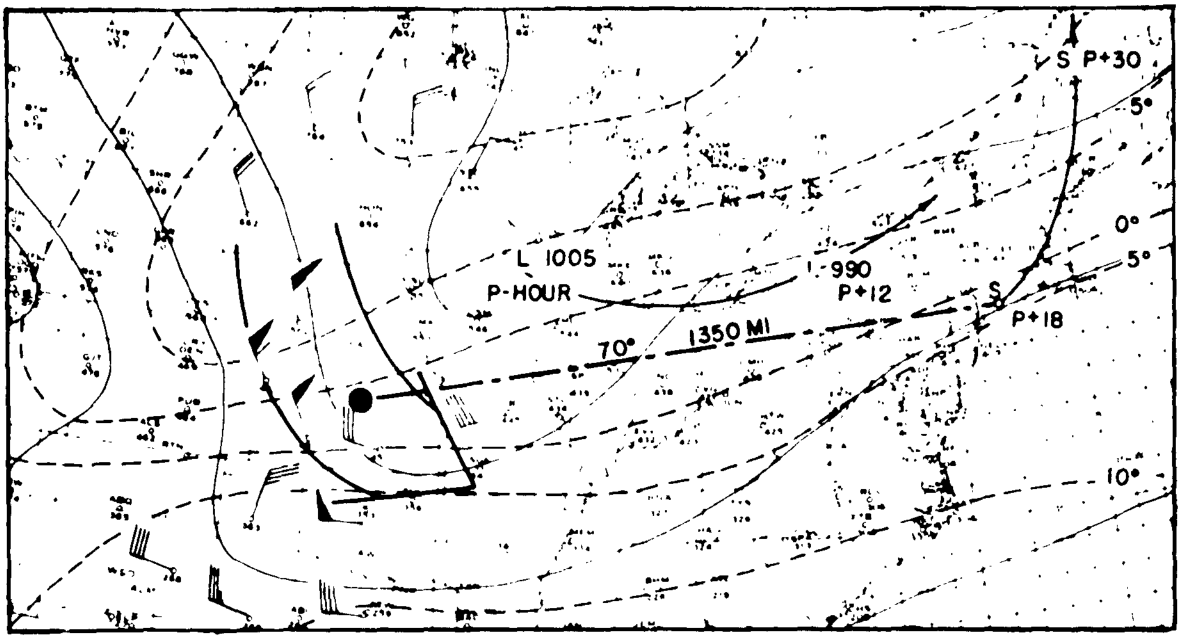
Some illustrations of the technique for forecasting cyclogenesis and the related problems are presented in Figs. 21 through 31, which are actual cases from the data sample (see Appendix I). The figure legends point out in each case pertinent features of the problem.

A sample worksheet for practical application of this forecasting technique can be found on page 50.

WORK SHEET FOR CYCLOGENESIS

ALWAYS WORK UNTIL STOP COLUMN CAN BE CHECKED OR SHEET IS COMPLETED

1. Does an injection exist? **STOP**
   (a) At 850 mb? ....
   (b) At levels below 850 mb? (See page **49**.)
   (c) Cold tongue at any level? (See page **39**.)
   If answer to *all 3* is no, then check stop column here and forecast no cyclogenesis of any kind. If yes, to 1(b) or 1(c) forecast in accord with instructions and if 1(a) proceed. ....
2. First date and time injection appeared . If injection has had continuity from preceding maps, will it simply act to deepen a previously forecast case of cyclogenesis (see page **24**). If answer yes, check stop column here ....
   If C_I is north of 37° latitude (see page **34**), check stop column here if appropriate. ....
3. Special cases.
   (a) Does a negative pattern exist at 850 mb? See Fig. 20. ....
   If so, forecast no cyclogenesis and check stop here. ....
   (b) Is the parent cyclone Special Category (see pages **38** and **114**). ....
   If so, forecast as instructed and check stop here. ....
   (c) Does a subjective review of the 500-mb chart indicate definitely unfavorable conditions for cyclogenesis? (Pages **34** and **99** and Fig. 63.) If so, consider all subsequent findings in this light.
4. Course of parent cyclone .. (deg).
   Predicted 18-hour position (location).
   If 18-hour future course is between 61 and 104 *and* 18-hour position lies in circle of Fig. 6, predict center jump from 18-hour position and check stop here (forecast instructions, page **29**). ....
5. If either condition in line 4 is not met, proceed to determine:
   (a) Distance between C_I and center of parent low miles.
   (b) Central sea level pressure of parent low mb.
   Consult Fig. 8. If point falls below the curve, forecast deepening of parent, no cyclogenesis and check stop. ...
6. If point in Fig. 8 falls above curve forecast cyclogenesis at east.
7. Location.
   (a) Construct kidney-shaped area on working chart from Fig. 10.
   (b) What is maximum range of temperature in isotherm ribbon in 350 miles? (°C).
   Forecast same latitude as C_I if $T = 15°$; for higher values move south in the kidney area, and for lower, northward.
   (c) What is mean orientation of surface front? (deg).
   The more north-south the front, the farther north cyclogenesis should be forecast (see Fig. 11 and page **32**).
   (d) If no parent low, forecast cyclogenesis in southwest portion of kidney.
   (e) If conflict in these indications forecast same latitude as C_I.
   Predicted location of cyclogenesis ....
8. Intensity.
   (a) 850-mb temperature range of injection ... (°C).
   (b) 850-mb average wind in injection .. (kts).
   Initial intensity of new storm from Fig. 13 ....
   (c) 500-mb trough sharpness (corrected for latitude by table on page **20**) (ft).
   (d) 500-mb temperature gradient 1000 mi. east of trough (°C).
   Storm intensity prediction Figs. 14, 15, 16 ....
9. Initial Course.
   (a) Orientation of contours 850 mb .... (deg).
   (b) Orientation of isotherms 850 mb. .... (deg).
   (c) Amplitude of isotherms .... (lat°).
   (d) Forecast intensity from Fig. 16 ....
   From average of 9(a), (b) corrected from Fig. 17, initial course is forecast as .... (deg).
10. Speed.
    (a) Representative geostrophic wind 850 mb .... (kts).
    (b) ΔT 1000 miles northwest from cyclogenesis (850 mb) .... (°C).
    From Fig. 18, speed is forecast for first 12 hours as .... (mph).
11. Verification.
    Center jump. Cyclogenesis. No cyclogenesis occurred. (Circle one).
    Time formed .... east. Location ....
    Initial: Track .... Speed .... Intensity ....
    Maximum intensity in 30 hours after formation ....
    Remarks:



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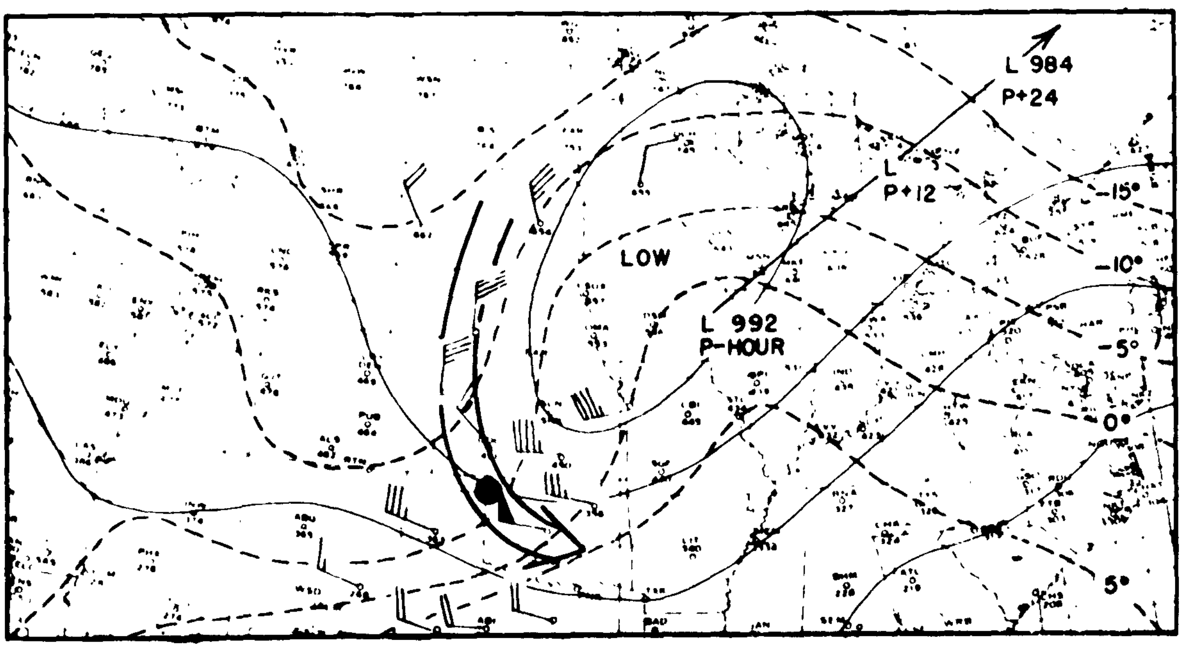

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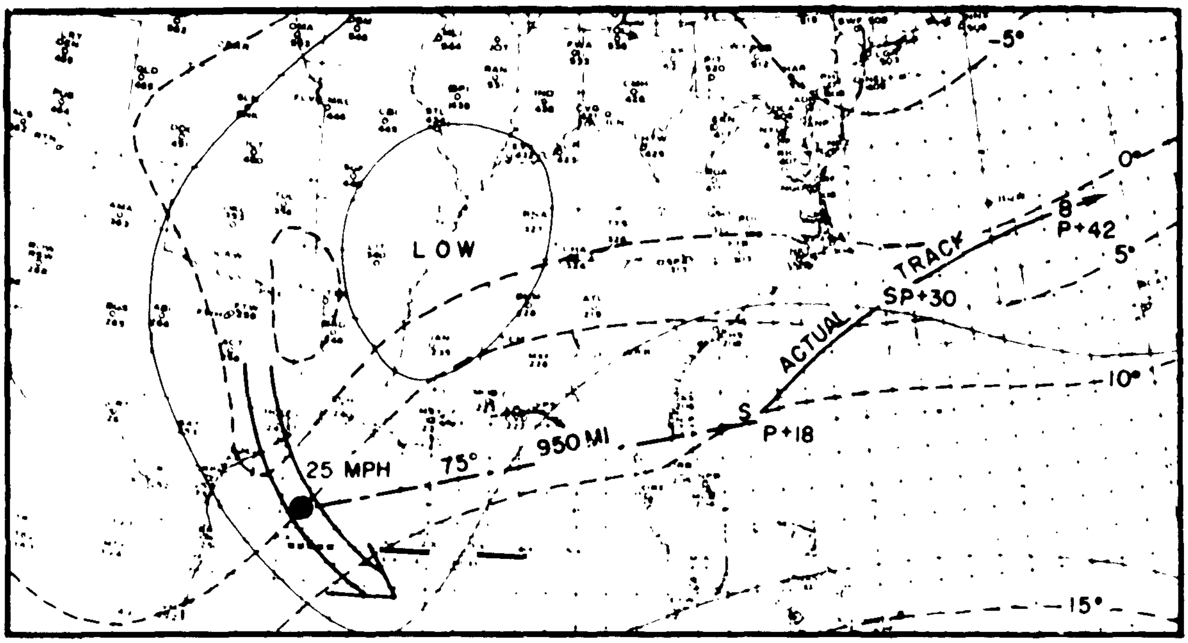

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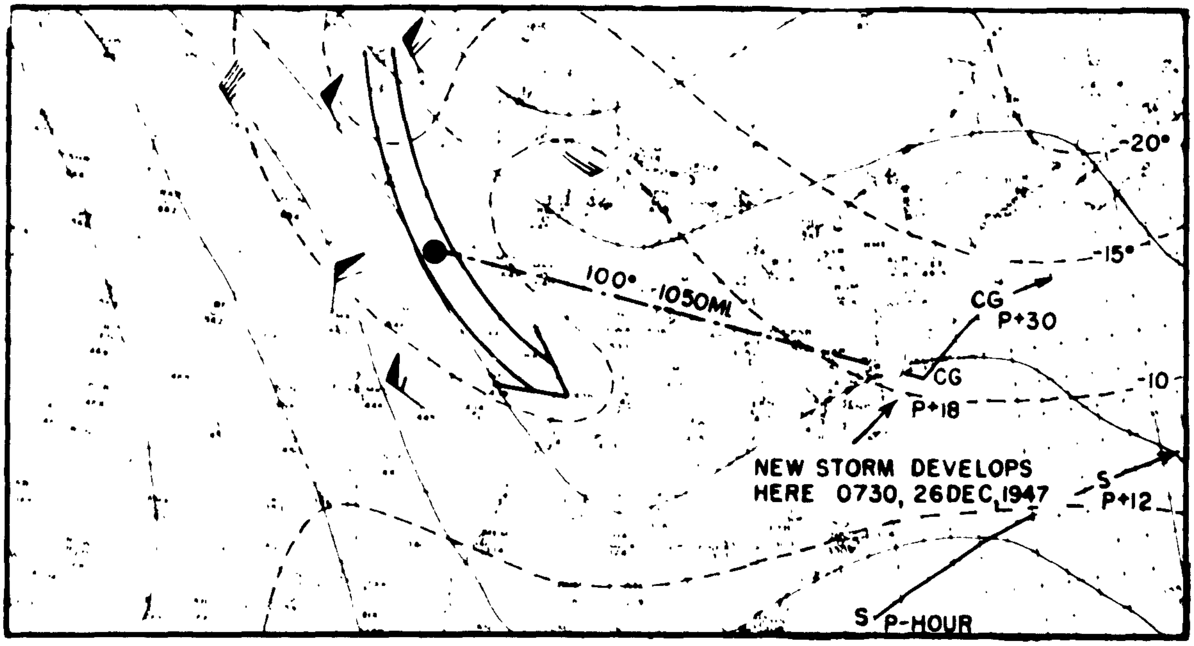

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STOP

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   If C_I is north of 37° latitude (see page **34**), check stop column here if appropriate. ...

3. Special cases.
   (a) Does a negative pattern exist at 850 mb? See Fig. 20. ...
   If so, forecast no cyclogenesis and check stop here. ...
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   (c) Does a subjective review of the 500-mb chart indicate definitely unfavorable conditions for cyclogenesis? (Pages **34** and **99** and Fig. 63.) If so, consider all subsequent findings in this light.

4. Course of parent cyclone (deg).
   Predicted 18-hour position (location).
   If 18-hour future course is between 61 and 104 *and* 18-hour position lies in circle of Fig. 6, predict center jump from 18-hour position and check stop here (forecast instructions, page **29**). ...

5. If either condition in line 4 is not met, proceed to determine:
   (a) Distance between C_I and center of parent low miles.
   (b) Central sea level pressure of parent low mb.
   Consult Fig. 8. If point falls below the curve, forecast deepening of parent, no cyclogenesis and check stop.

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7. Location.
   (a) Construct kidney-shaped area on working chart from Fig. 10.
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   Forecast same latitude as C_I if $T = 15°$; for higher values move south in the kidney area, and for lower, northward.
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   (a) 850-mb temperature range of injection (°C).
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   (c) 500-mb trough sharpness (corrected for latitude by table on page **20**) (ft).
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   (a) Orientation of contours 850 mb ... (deg).
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   From average of 9(a), (b) corrected from Fig. 17, initial course is forecast as ... (deg).

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   (a) Representative geostrophic wind 850 mb ... (kts).
   (b) ΔT 1000 miles northwest from cyclogenesis (850 mb) (°C).
   From Fig. 18, speed is forecast for first 12 hours as ... (mph).

11. **Verification.**
   Center jump. Cyclogenesis. No cyclogenesis occurred. (Circle one).
   Time formed ... **east. Location** ...
   Initial: Track . Speed ... **Intensity** ...
   Maximum intensity in 30 hours after formation ...
   Remarks:

CATEGORIES I AND II CYCLONES

R. D. ROCHE AND H. B. VISSCHER

1. CATEGORY I CYCLONES

1.1. INTRODUCTION

By definition, Category I cyclones are those that are located beneath a broad belt of northwest flow at 700 mb and move from the northwest. They constitute a distinctly different type of cyclone from the more usual U. S. low (beneath southwest flow aloft) that has been the object of most meteorological cyclone research. Further, although the occurrence of these lows in North America is limited to the broad area comprising the lee of the Rocky Mountains, they present a forecast problem to a large region of the northern plain states and central Canada. The locations of all Category I cyclones considered in this report have been shown in Fig. 32. Whether or not Category I lows are indigenous to "lee of the mountain" areas outside of North America is not known. Category I cyclones are not unusual; they occur on an average 3 to 4 times per month in the winter season.

This investigation presents pertinent facts concerning the origin of North American Category I cyclones, and discusses in detail specific forecasting problems of development and movement. The sea-level cyclonic systems investigated, and those to which the forecasting methods are applicable, are low-pressure areas with one or more closed isobars and with clear evidence of a cyclonic wind field.

1.2. DATA

The research on Category I cyclones was based on four winter seasons of data, from November 1947 through March 1951; these cyclones are case numbers 1 through 64. Appendix II presents the information for each case. The season November 1951 through March 1952, containing 35 cases (case numbers 65 to 100) provided an independent data group for control purposes. Appendix III covers this data.

The initial analysis of each case is made when Category I requirements are first fulfilled, i.e., a reasonable sea-level cyclone is located under northwest flow at 700 mb, with a past track of 6 to 12 hours from the northwest. In the control group of data, subsequent 12-hour positions of the same cyclone, still classified as Category I, are included as independent cases. No Category I cyclones were found south or east of the area in Fig. 32; some cyclones north and west of this area could not be studied because of data limitations.

1.3. ORIGIN

The boundaries of the synoptic maps prevented research on Category I lows north of 60° N latitude and west of the Canadian-United States Rocky Mountains. However, the paths of cyclones were traced back to their origin, or for a minimum of 24 hours, or to the limits of the sea-level synoptic charts (about 65° N latitude and 135° W longitude). The northern hemisphere sea-level charts could not be utilized because of the 24-hour interval between successive maps. The modes of origination of Category I lows, and some details concerning each, are presented below.

1.31. *The Cyclone Moves in as a Separate Cell from the Far Northwest*

About 30 percent of the Category I cyclones were traced back to the Yukon-Mackenzie-Alexander islands area, and reasonable evidence was found of clear-cut movement from this area to the Category I location of the low. The distinction between a cyclone in this group and a cyclone in the following group (which forms in a northeast-southwest trough) is not always evident. If the cyclone was followed by a sea-level high-pressure ridge, the low was cataloged as "moves in." The typical 700-mb pattern shows a

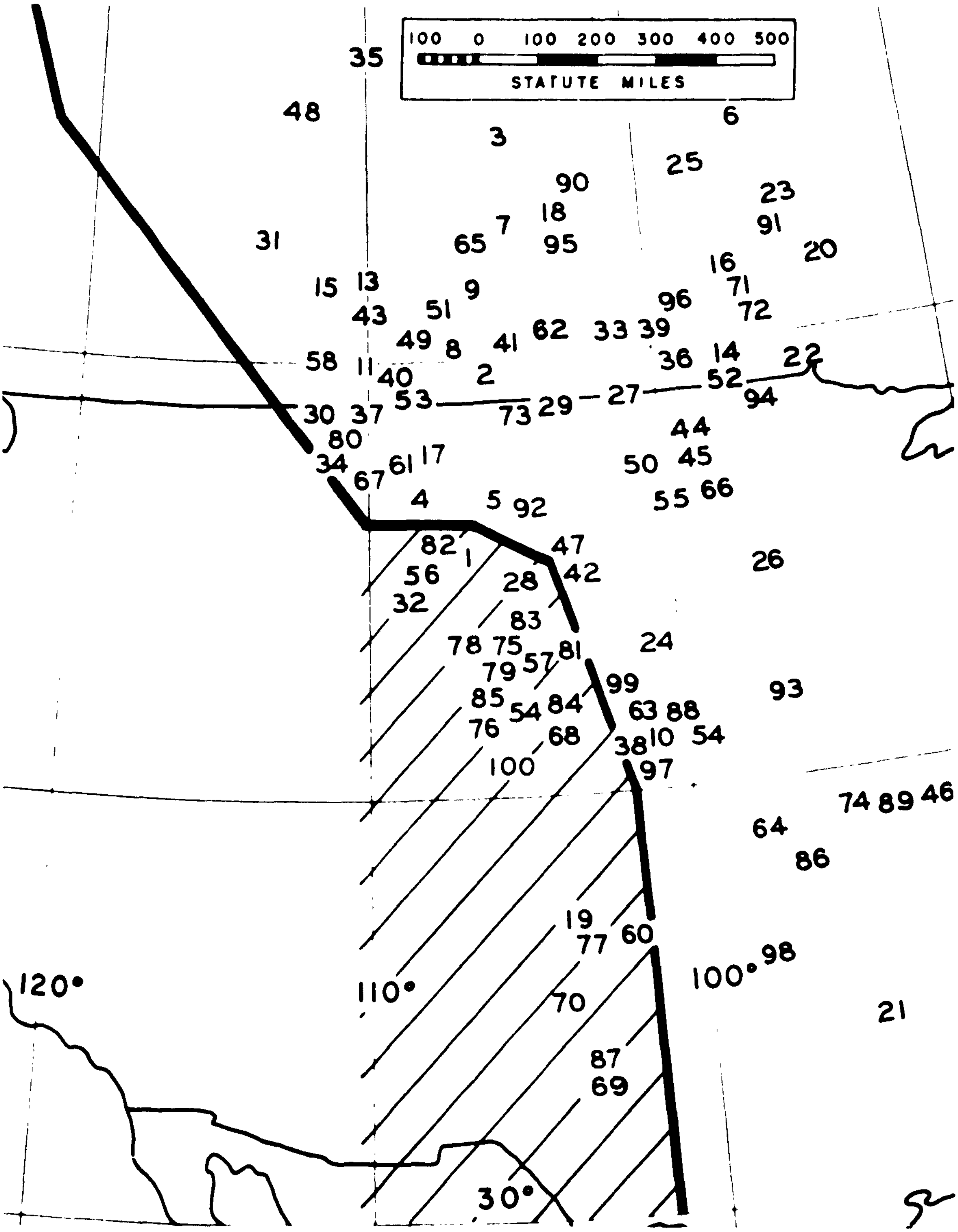


Fig. 32. Original location of Category I cyclones. The positions of all Category I cyclones (cases 1 through 100) are shown above. The cross hatching delineates the mountain area and its slopes which influence cyclone movement. Numerals indicate case numbers.

low in the Hudson Bay area and a major ridge of high pressure north-south from the Arctic Circle down the west coast of North America. The ridge is usually located from 115° to 140° W longitude. This ridge aloft remains almost stationary as the sea-level cyclones move southeastward. In 12 to 24 hours, the cyclone has crossed the 700-mb ridge line and lies beneath northwest flow at 700 mb. It is then a Category I cyclone.

1.32. *The Cyclone Forms in a Northwest-Southeast Trough Which Extends from a Major Low in the Gulf of Alaska*

Nearly 40 percent of Category I lows are present due to the following mechanism. On the surface chart, a large well-formed cyclone is present in the Gulf of Alaska (defined in the broadest sense as covering the area from central Alaska to the latitude of Vancouver). From this semipermanent low, a trough extends eastward to the Canadian Rockies and thence southeast down the east side of the mountains into Montana and Wyoming. The new Category I low cell may first form at the time an occlusion moves inland in the Washington area. Often this is not easily determined, because of analytical difficulties. The first appearance of the low is in the lee of the mountain area in Alberta and Montana. At 700 mb, the north-south ridge of high pressure is not so pronounced in the majority of cases as in the first mode of origin. The initial appearance of the low is often small, weak and shapeless. Some 18 to 24 hours after the first closed isobar forms, the cell will have assumed a definite shape, and will belong to Category I.

1.33. *The Cyclone Forms in a North-South Trough Which Extends South from the Arctic Circle Region*

Category I lows of this origin are only 15 percent of the sample. The mechanism is, however, very clear cut. An elongated trough terminating north of the Arctic Circle extends south into Canada and the United States in the lee of the Rocky Mountains. As this trough moves slowly east, cyclogenesis occurs in the trough south of 60° N latitude. The upper-air contour pattern is similar to the first mode of origin, with a large north-south ridge of high pressure at the west coast of North America and a Hudson Bay low. As in the other modes, since the surface system is not initially reflected in the 700-mb contour pattern, the newly formed cell belongs to Category I. It is interesting to note in passing that, whereas most Category I cyclones steer with the 700-mb contour pattern, those few cases which do deviate markedly from the steering current had their origin in these north-south troughs.

1.34. *The Cyclone Is Produced by Cyclogenesis Not Related to a Well-Defined Trough*

Nearly 15 percent of the Category I cyclones originate without apparent assistance from a parent low, and outside of a well-delineated pressure trough. In contrast to the other modes of origin, these cells generally form south of 45° N latitude and near the mountains. There appears to be no reason, however, why this occurrence cannot take place in any area. It is doubtful if forecasting parameters valid for other types of cyclogenesis can be applied to this type of low. They are often very close to the mountains, and present unusual synoptic patterns. The upper-air pattern is again similar to the other groups. The sea-level pressure patterns are generally weak and flat.

Table 1 of Appendix II presents the data on the origin of Category I cyclones; however, it has been found that the development and movement of these storms are independent of the mode of origin.

1.4. DEVELOPMENT OF CATEGORY I CYCLONES

The growth or decay of cyclones moving from the northwest under northwest flow aloft presents a problem to the forecaster in the United States. Many cyclonic storms seriously affecting the weather in the central and eastern United States originate in this manner. Category I cyclones are prone to fill or to persist

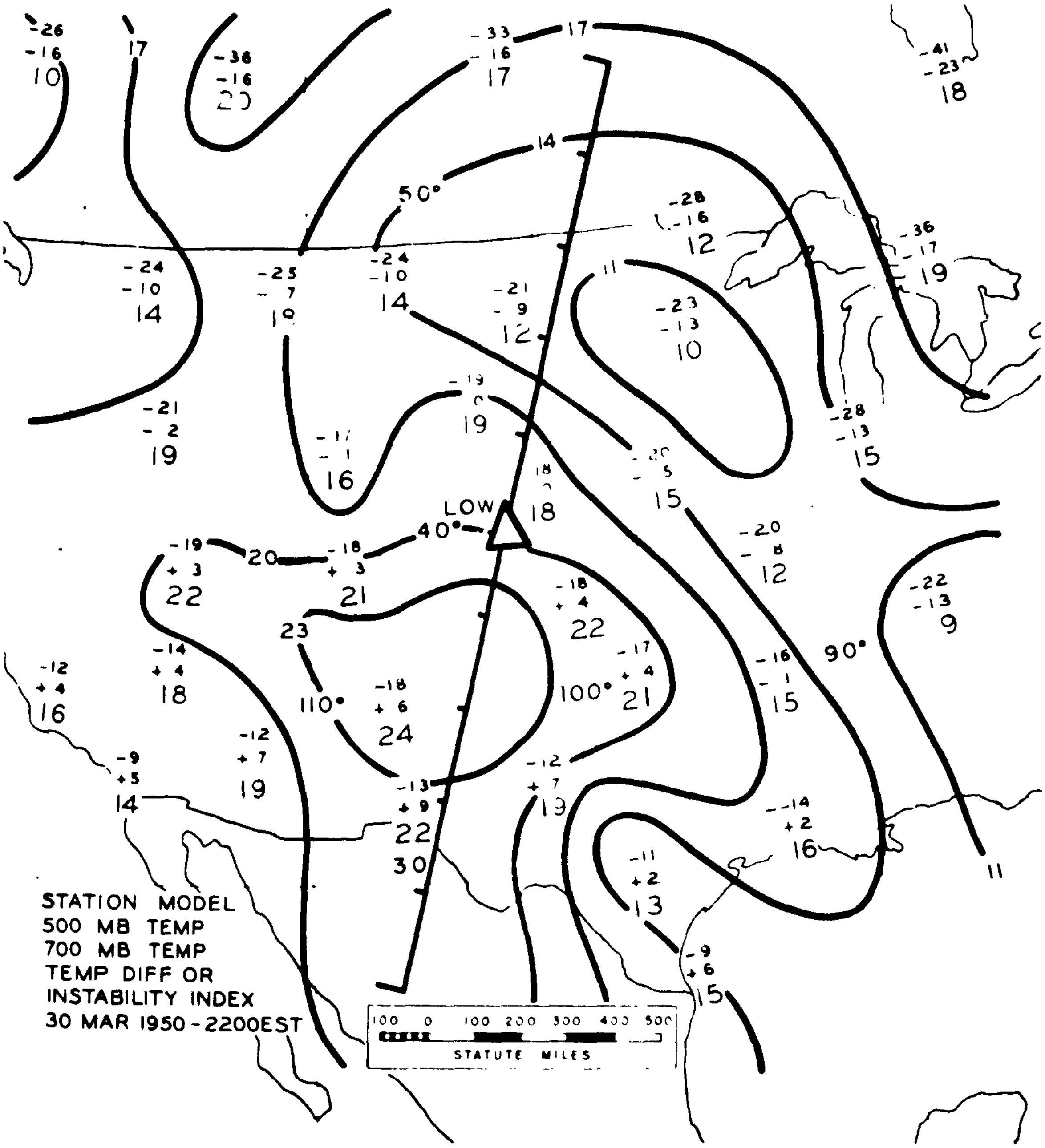


Fig. 33. Instability index isopleths for a nonfilling Category I cyclone. Note the instability area southwest and the stable area northeast of the cyclone position, and the instability index gradient oriented northeast-southwest. The axis through the low center is perpendicular to the 700-mb contours.

without appreciable deepening. This is in contrast to Category IV lows which frequently deepen. Consequently, the forecast problem is to determine the rate of filling, i.e., the number of hours until complete disappearance from the weather map. Cyclones which persist for longer than 18 hours are called "nonfilling."

A search for those measurable features of the synoptic charts which might distinguish the filling from the nonfilling cyclones is simplified when the cyclones under consideration are all in a similar area of the

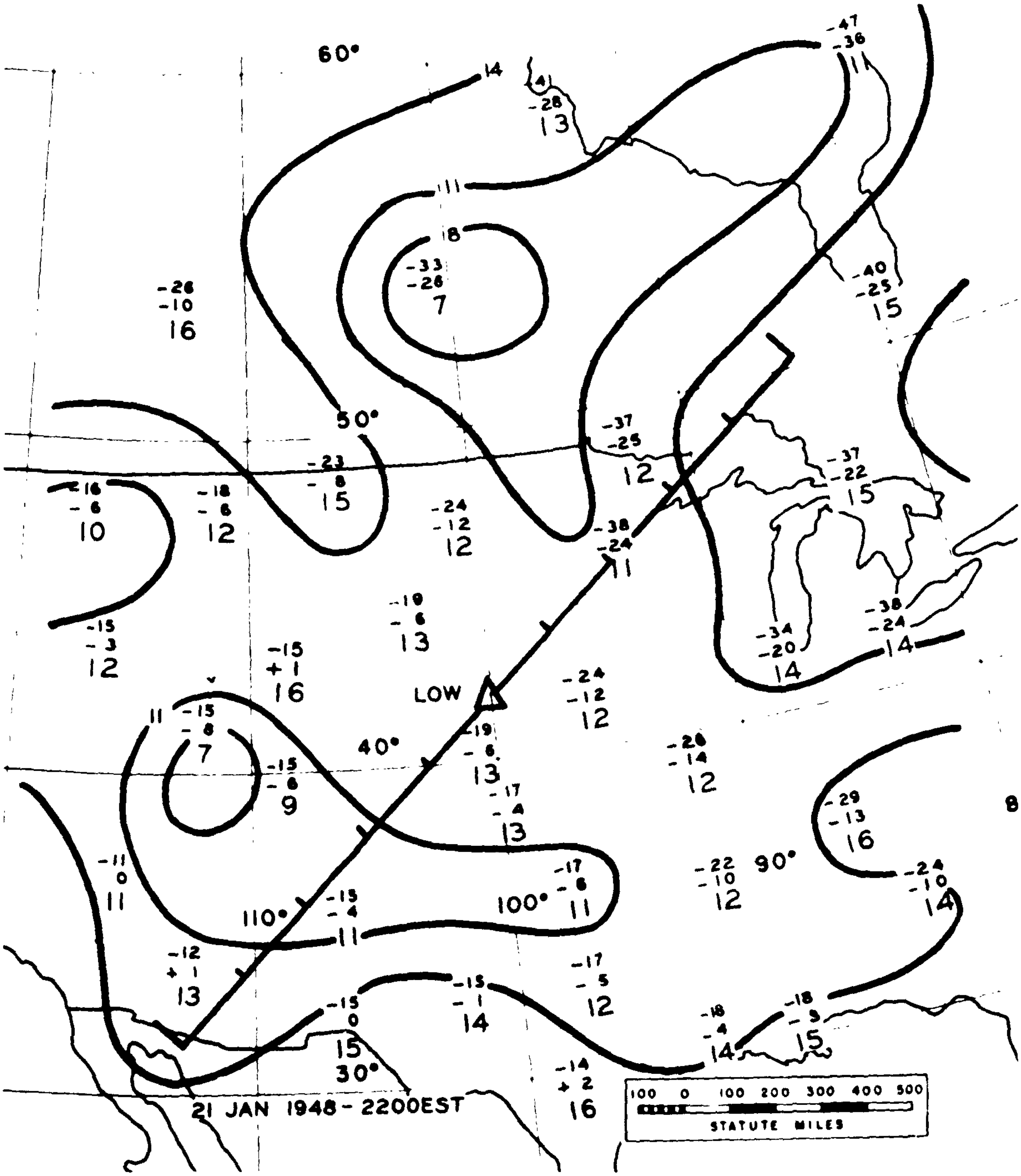


Fig. 34. Instability index isopleths for a filling Category I cyclone. Compare the ill defined patterns above with the patterns of Fig. 33. The legend is the same as for Fig. 33.

wave pattern aloft. This is the case with all Category I lows which are located beneath northwest flow aloft with a high uniformity in the contour pattern. It was logical to assume, therefore, that the upper-air thermal patterns would provide features necessary to define the future development of the cyclone. The

initial investigation by George (1949), defining the "isotherm ribbon" and pointing out its relationship to development, further emphasized the importance of isotherm patterns to the synoptic forecasting problem. A direct extension of the isotherm ribbon concept to Category I cyclones did not provide for adequate forecasting of their development. It became evident that a three-dimensional treatment of the isotherm ribbon idea was necessary.

By plotting the temperature differences between any two upper levels for each reporting point and by drawing isopleths of these differences, the change with height of the isotherm pattern is defined. Figures 33 and 34 are examples of such maps, illustrating in these cases, the temperature differences between the 700-mb and 500-mb levels. These isopleths also illustrate variations in lapse rate over the region. For this latter reason, the isopleths are called lines of instability and the individual temperature differences are called instability indices.

Two composite maps of these isopleths of instability were drawn for each of several layers, one for average values of filling Category I lows and the other for average values of a group of nonfilling lows. These composite maps disclosed several important features (some of which are apparent in Figs. 33 and 34).

1. The lines of instability for the 700- to 500-mb layer illustrated distinct differences between filling and nonfilling cyclones. The 850- to 700-mb and 850- to 500-mb layers did not emphasize the contrast so well.

2. Instability gradients are weak and ill-defined for filling lows. For nonfilling lows, a definite isopleth pattern was apparent.

3. The maximum gradient of instability was directed northeast-southwest through the position of the sea-level cyclone on the nonfilling composite map. In the case of filling cyclones, almost no gradient was shown along this line.

4. The 700- to 500-mb composite charts indicated that the pertinent features of the instability patterns were within a radius of 1000 miles from the low center.

It was then determined that these differences between filling and nonfilling cyclones, so apparent on the composite charts, also applied with reasonable consistency to the individual situations. The instability pattern charts (e.g., Figs. 33 and 34) provide in themselves, therefore, the first useful forecasting parameter for the development of Category I cyclones. However, these instability pattern maps are difficult to evaluate objectively. Further, it would be undesirable to introduce an additional map plotting routine. Since the pertinent features of the charts lay along a northeast-southwest axis through the low center, and within 1000 miles of the low, it was necessary to plot and evaluate only the instability index values along such an axis. Specifically:

1. On both the 700- and 500-mb maps, identically placed axes were drawn perpendicular to the contours at 700 mb through the low center position. The 0130E or 1330E position of the sea-level low is used,[1] without adjustment for the 3-hour time lag between

[1] Not infrequently, the cyclone being studied will be of a double-center structure on the sea-level chart. Usually, it is apparent that the system is fundamentally one cyclone. Each center should be treated completely by this technique and the longest duration forecast may be assumed to be correct. This does not imply that *that* center will be the one to take over within the cyclone. It *does* imply that the major cyclone is located under a portion of the upper air which is favorable to persistence, that eventual merging will occur and that the resulting low will persist as the graph indicates.

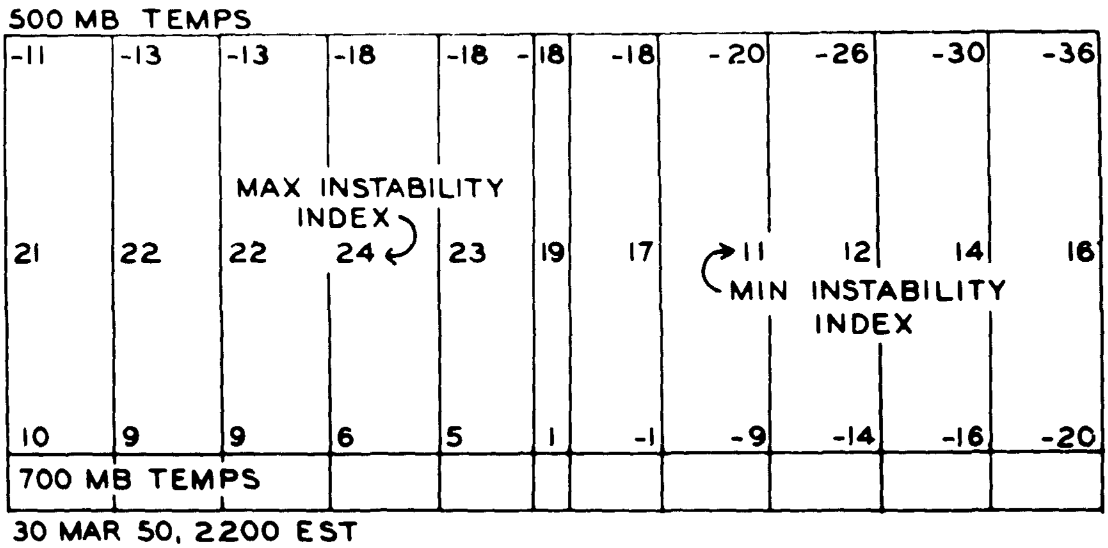


Fig. 35. Thermal cross section illustrating the instability index value and the "profile" of indices along the axis perpendicular to the 700-mb northwest flow. (The indices shown are from the axis in Fig. 33.)

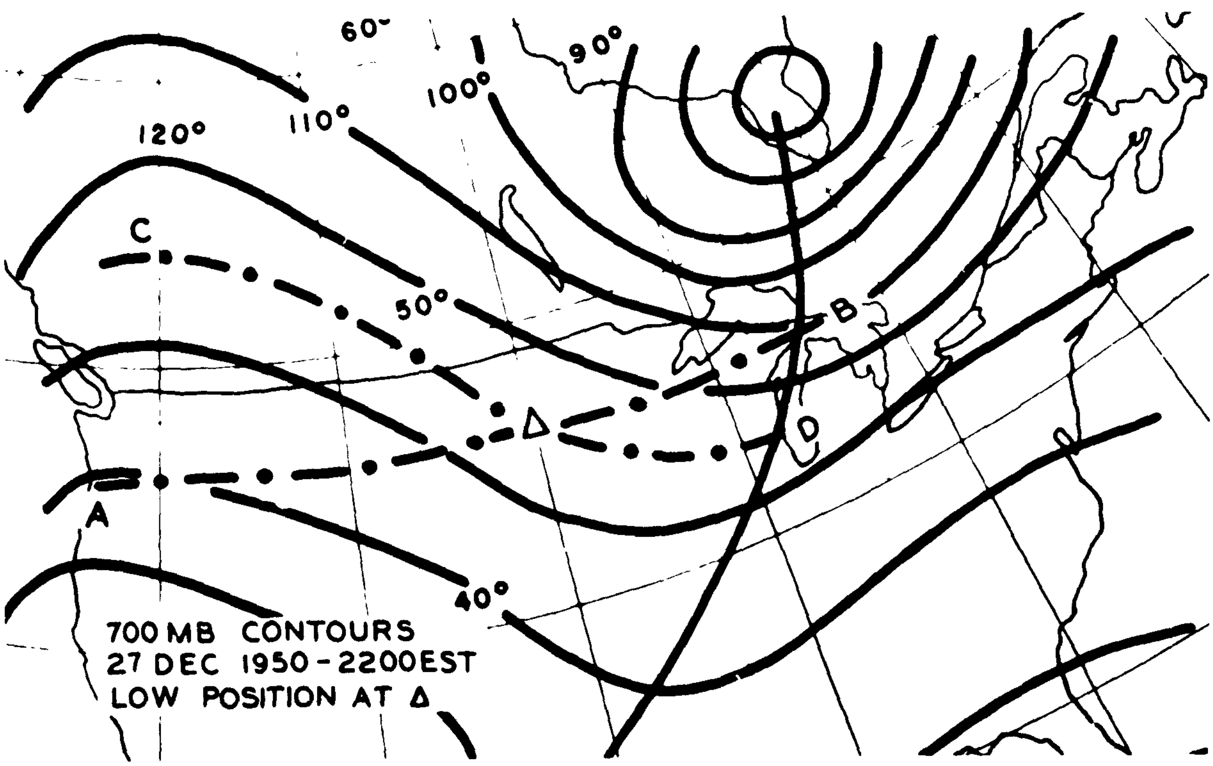


Fig. 36. The half wavelength and amplitude. The half wavelength is the distance (in degrees latitude) from the ridge at *A* to the trough at *B*, and the amplitude is the latitude difference *C* to *D*.

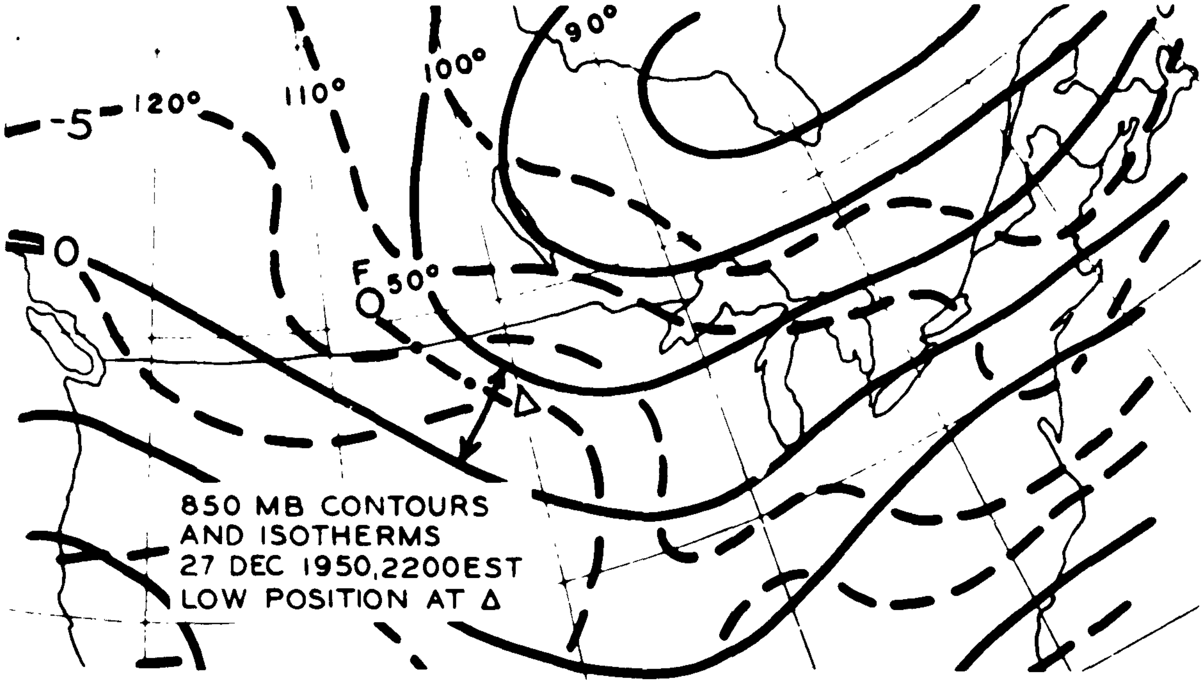


Fig. 37. The advective term. The point F is upstream from the low center, a distance 24 hours times the geostrophic speed measured at the low center. The temperature difference between the low center and the point F is the advective term.

sea-level and upper-air charts. These axes extend 1000 miles, both northeast and southwest of the low center. At 700 mb, the axis may be thought of as a line along the maximum contour gradient; also, it usually lies along the maximum thermal gradient and the maximum instability index gradient for the layer between the levels.

2. Temperature values at 200-mile intervals along the axes were determined at both 700- and 500-mb levels.

3. The difference in temperature between the 700- and 500-mb levels at each 200-mile interval (the instability index) was then determined.

The net result is a simple set of instability index values along a line through the low center and at right angles to the 700-mb contour flow. Figure 35 illustrates diagramatically such a thermal cross section and the final result, the set of index values.

If a profile of the index values for each cyclone is now drawn, the distinction between filling and nonfilling Category I cyclones becomes apparent. Nonfilling cyclones exhibit high index values in the southwest portion of the axis (in the warmer air) and relatively low index values in the northeast (in the cold air). Filling cyclones, on the other hand, have a meandering profile with no clear-cut maximum or minimum value, or only small differences between the maximum and minimum values. This difference is called the instability contrast. It proved to be the primary parameter in the development forecast for Category I cyclones.

A frequently considered factor in cyclogenesis is wavelength. Therefore, it was logical to investigate

the relationship between development of Category I cyclones and wavelength. It was found that a definite correlation was present: the greater the wavelength of the 700-mb contour pattern, the more likely the occurrence of a nonfilling Category I cyclone. The wavelength parameter used was the measurement at 700 mb of the half wavelength in degrees latitude measured along the latitude of the low cell from the western ridge line to the eastern trough line. This is illustrated in Fig. 36.

The natural partner of wavelength is amplitude. This, too, was investigated and it was found that for a given wavelength, there was a preferred amplitude favoring nonfilling of Category I cyclones. The amplitude factor is the measurement at 700 mb of the amplitude in degrees latitude. This is made by following the contour over the low upstream to the most northern latitude and downstream to the most southern latitude.[2] The difference is the amplitude. This is illustrated in Fig. 36.

At this stage of the research on development of Category I cyclones, there are three parameters: instability contrast, wavelength, and amplitude. When the preliminary correlation of instability contrast and wavelength was tested with an additional data group, however, it was apparent that the investigation had not included a fourth factor traditionally of importance in development, namely a consideration of advection. It was necessary to analyze and introduce quantitatively the temperature advection field either as a primary factor or as a corrective term. The most satisfactory yardstick for this advective component was determined as follows: measure the geostrophic wind velocity at 850 mb over the low center,[3] and move "up contour" this velocity times 24 hours. The difference between the temperature at this point and over the low is the advective term. It is negative if colder air is encountered in proceeding upsteam. This is illustrated in Fig. 37.

The four parameters may all be measured objectively. Table 2 of Appendix II presents the pertinent values. By means of multiple correlation techniques, they were correlated for each cyclone in the data sample to achieve a forecast of the number of hours until filling.

Stage 1 of the multiple correlation, relating the instability contrast with the advective term, is presented in Fig. 38. Each cyclone in the basic data group was entered on this chart. The family of curves was fitted by inspection and arbitrarily numbered from 0 to 7. The stage 1 curves give good separation between filling and nonfilling cases. The construction was designed, however, to give optimum separation on the final composite graph only.

Stage 2 of the multiple correlation is presented in Fig. 39, and correlates the half wavelength with the amplitude. Again, the family of curves was to give optimum results only when combined with stage 1.

Using stage 1 value as the abscissa and stage 2 as the ordinate, the final and composite graph is attained and is shown in Fig. 40. Primarily, the final graph provides separation between filling and nonfilling cyclones of Category I; in addition, it measures the rate of filling. The stage values and the forecast results are tabulated in Table 2 of Appendix II.

The following conclusions may be drawn by referring to Fig. 38:

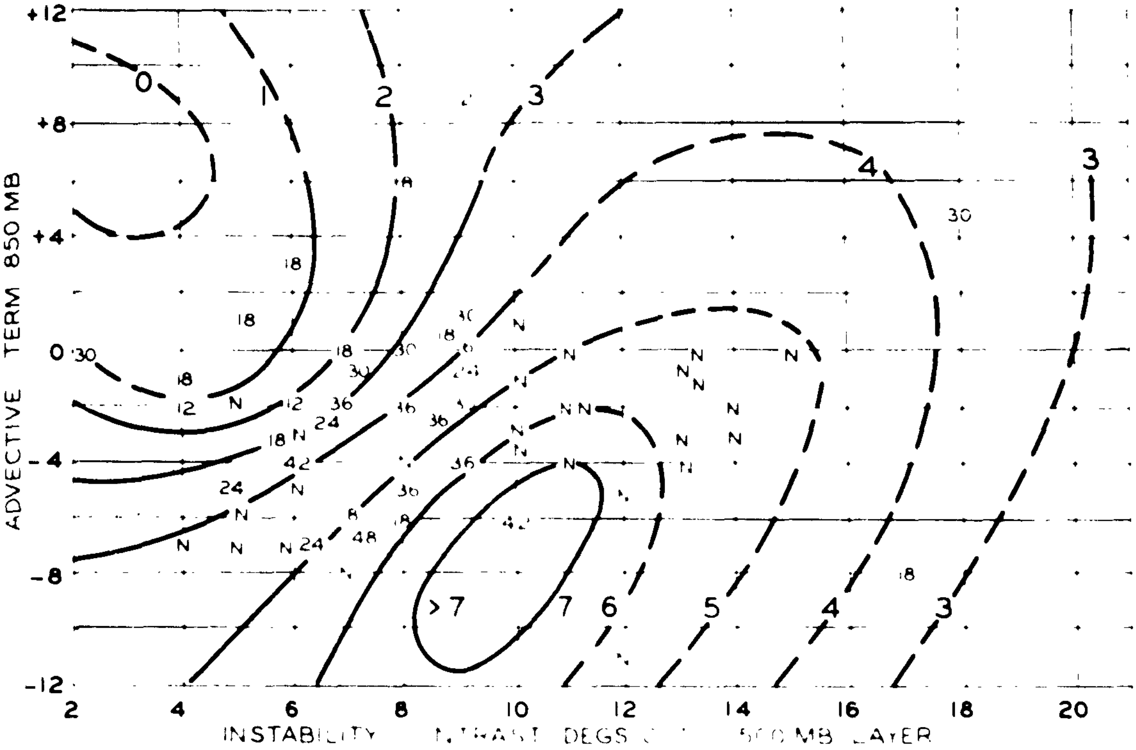
1. With a constant advective term, the larger the instability contrast the greater the tendency for the low to persist up to a certain high value near 14–16. Beyond this point, the trend may be toward filling. Insufficient data in this graph area prevent definite conclusions.

---

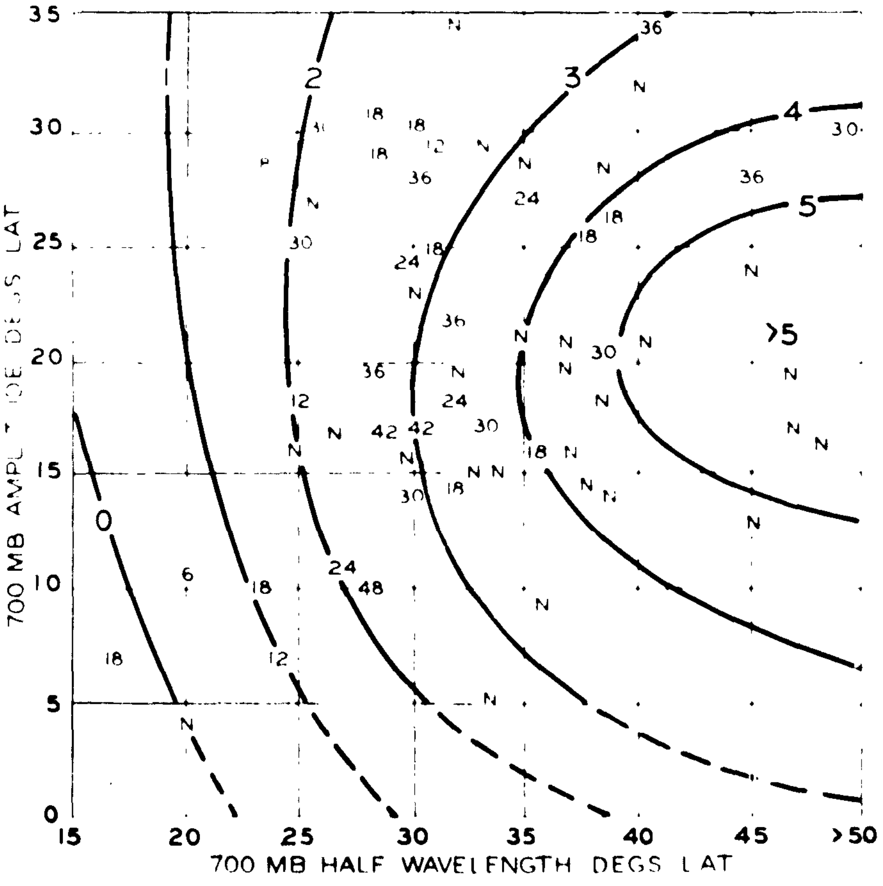
[2] If the contour over the low center is closed, estimate the amplitude parameter from the nearest open contour.

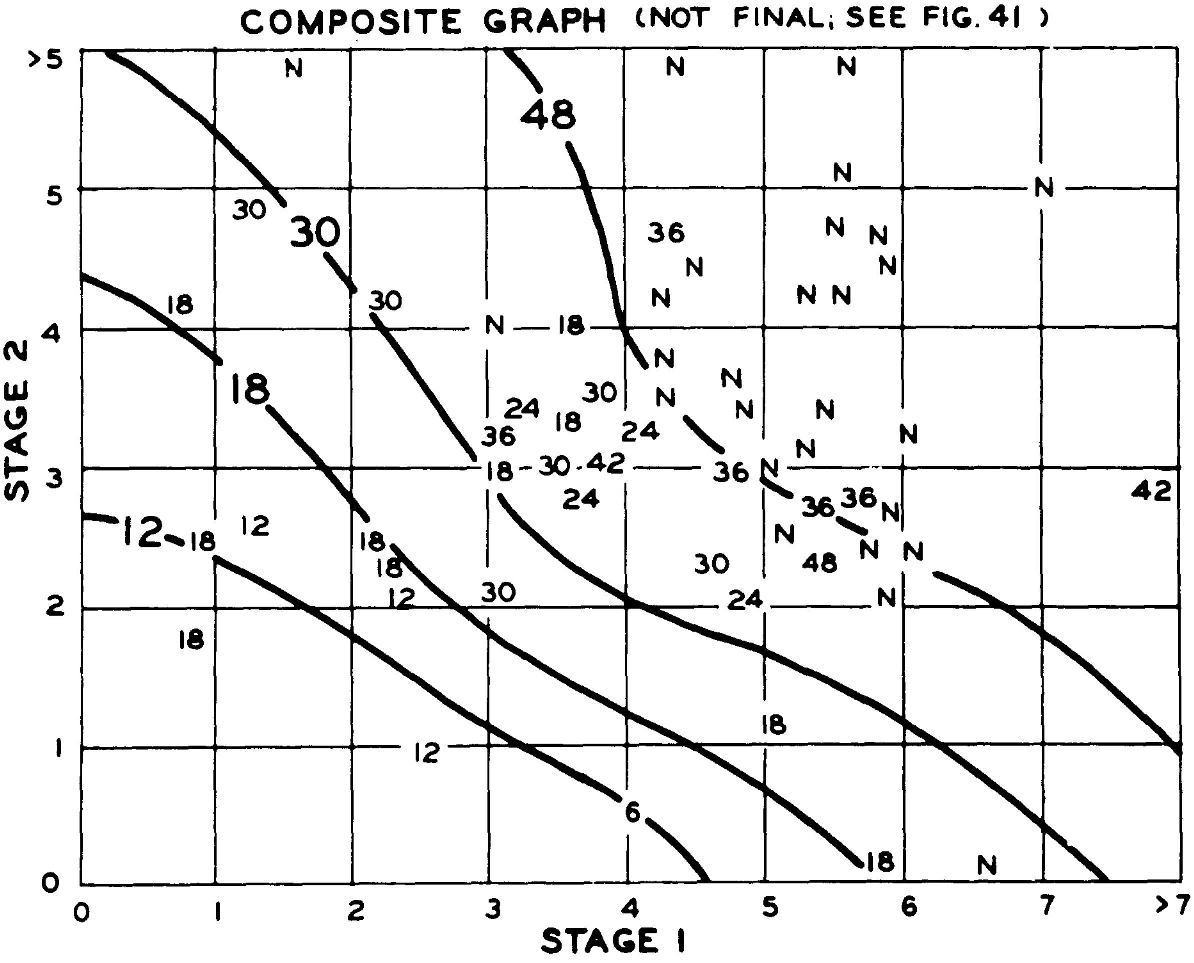
[3] If very nearly in the center of a closed cell, assume a speed of 5 knots in the direction of the prevailing upstream flow.

STAGE 1



STAGE 2





Open circles ◦ with "N" adjacent represent cyclones which did not fill within 48 hours. Filled circles ● with numerals as "36" hours adjacent represent filling cyclones.

STAGE 1. Fig. 38. Instability contrast. Draw an axis on the 500- and 700-mb charts perpendicular to the 700-mb contours over the surface low center. Determine temperature differences 700 mb minus 500 mb at 200-mile intervals along axis 1000 miles either side of low. Subtract minimum index (NE of low center) from maximum (adjacent or SW of low center), this difference is the contrast.

Advective term. Measure the geostrophic wind velocity over surface low center at 850 mb. Move up-contour this velocity times 24 hours. From temperature at this point subtract temperature at the low center; this is the advective term. Negative values show cold advection. See Fig. 37.

STAGE 2. Fig. 39. 700-mb half wavelength. Measure in degrees latitude along the parallel over the low center from the ridge line west of the low to the trough line east. See Fig. 36.

COMPOSITE GRAPH. Fig. 40. If point falls to the right of the 48-hour line, the cyclone will persist for at least 48 hours, or will deepen. If point falls within the family of curves, the number of hours until filling is indicated.

THIS GRAPH HAS BEEN REVISED, SEE FIG. 41

To apply Figs. 38, 39, and 41 to Category II cases, the instability contrast axis is drawn perpendicular *to past track of the low*; no change in other parameters.

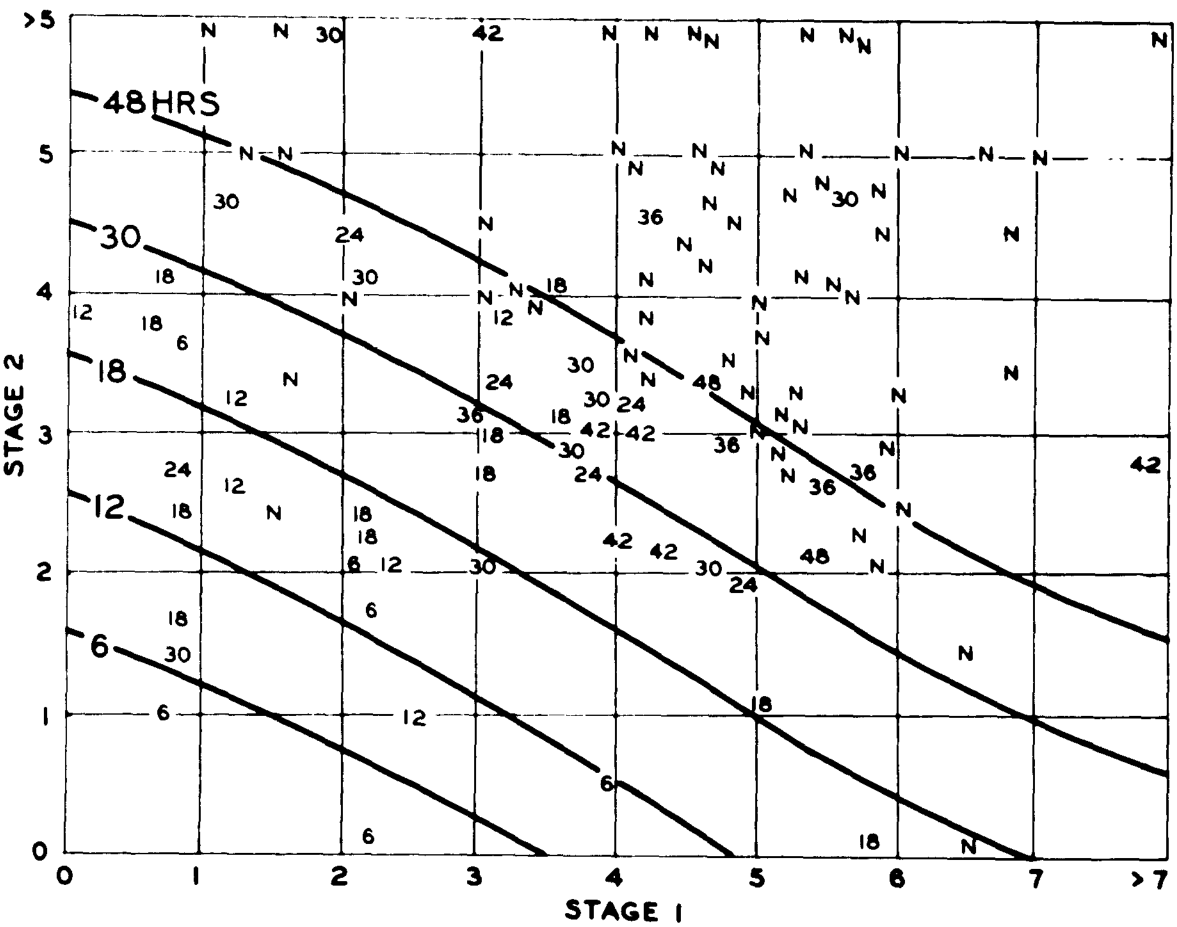


Fig. 41. Same as for Figs. 38, 39, and 40.

2. With a constant instability contrast, a large negative advective term (cold advection) promotes nonfilling; as the advective term decreases, the cyclone has less tendency to persist, until, upon reaching a positive advective term (warm advection), filling is marked.

It may be stated from Fig. 39, that:

1. Regardless of the amplitude, the longer the half wavelength, the greater the tendency to persist or deepen.

2. If the half wavelength is considered constant, there is a preferred amplitude for persistence which is in the range of 15° to 25° latitude.

The following conclusions may be stated from the composite graph of Fig. 40:

1. Stage 1 and stage 2 parameters contribute about equally to the separation of the cases. The final combination is superior to either stage 1 or stage 2 considered separately.

2. Category I cyclones separate into filling and nonfilling types and the graph provides a measure of the rate of filling. No conclusions can be drawn as to the rate of *deepening* for cases lying within the nonfilling zone of the composite chart, though about half of these

did deepen within 48 hours. Those Category I cases which did deepen had usually changed to Category II, III or IV by the time deepening had occurred. This was due either to a movement of the low east of the 700-mb trough or to the formation of a trough just west of the cyclone.

To test the validity of the forecasting technique presented above, a control group of Category I cyclones was examined. The distribution of the new cases throughout stage 1 and stage 2 families of curves was remarkably similar to that of the original data. The values of the four parameters for each case within the control group are listed in Appendix III. The additional data did indicate the necessity for a slight change in the curve slopes on the final composite graph in one area. This has been accomplished and Fig. 41 presents the corrected composite graph. In this diagram, the total sample of Category I cases has been entered and Category II cases have also been included.

It is not within the province of this project to establish theoretical justification for the four parameters which have proved effective; however, some indications of the line of thought on this score are provocative. Bjerknes and Holmboe (1944) and others have established that divergence over a surface cyclone is a requirement for the cyclone to maintain or increase its intensity. An analysis of the longitudinal divergence distribution in the northwest flow portion of a wave pattern aloft (Bjerknes, 1944) indicates a requirement of low-level and high-level convergence layers and an intermediate layer of divergence. The heights of the boundaries of this divergence layer (the upper, the level of nondivergence, the lower, the level at which the mean zonal wind equals the speed of the wave pattern) are functions of the mean zonal wind, the speed of the wave pattern and the critical wind speed. It is assumed that the deeper the intermediate divergence layer, the greater the tendency toward cyclogenesis.

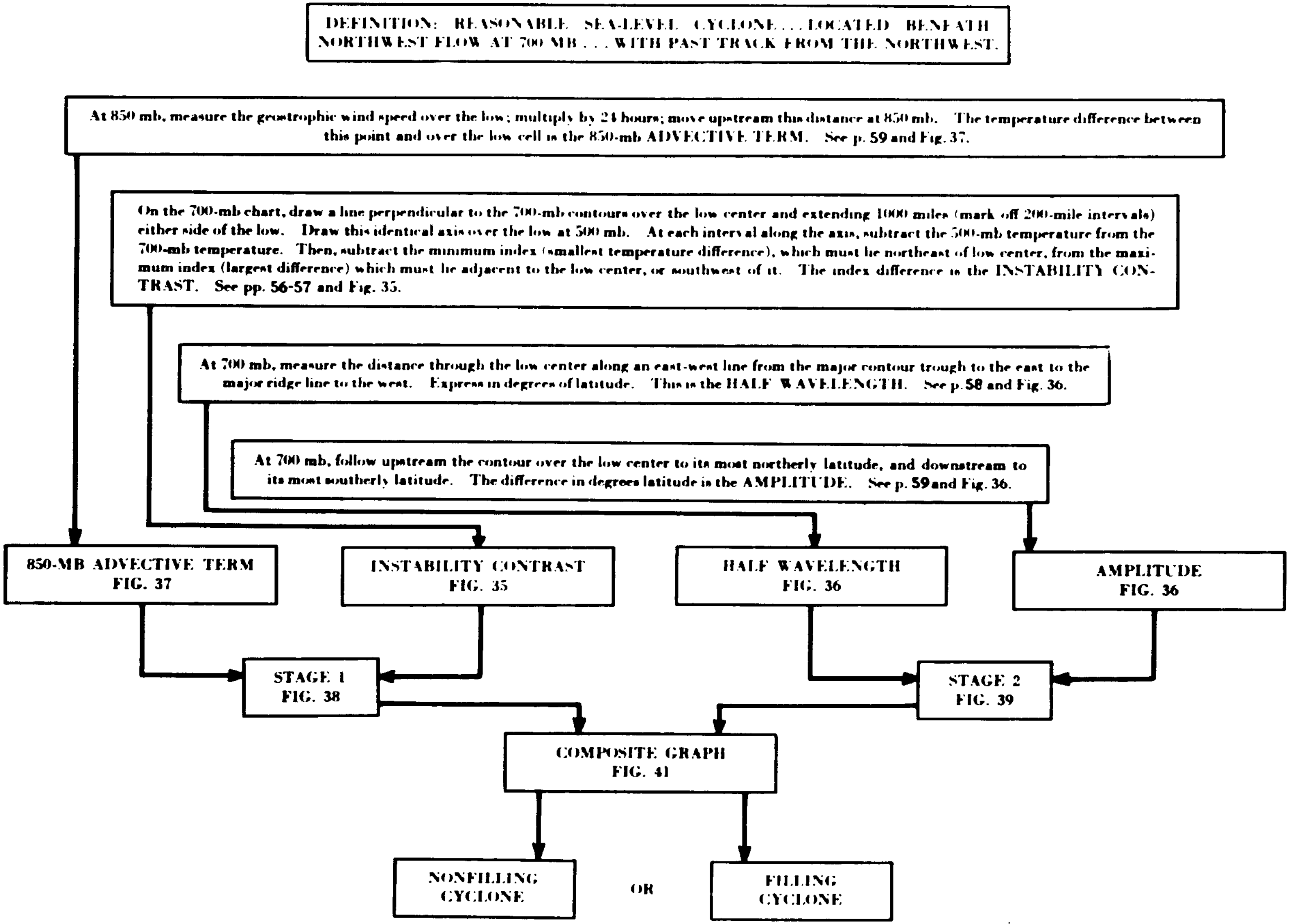
Large values of the instability contrast parameter determine two features of the three-dimensional temperature pattern: (1) a marked temperature gradient at 700 mb and (2) a rapid decrease of temperature gradient from 700 to 500 mb. These in turn are associated with a rapid increase of wind with height in the lower layers to above 700 mb but below 500 mb, and with a small increase of wind with height at 500 mb and above. This wind field system results in a high upper boundary and a low lower boundary of the divergence layer; therefore, it contributes to a deep longitudinal divergence layer. It is plausible, therefore, that large values of the instability contrast are associated with *nonfilling* Category I cyclones.

The relationship of wavelength to wave development has received much attention in meteorological literature. Referring to waves along a sloping frontal surface near sea level, Petterssen (1940) has postulated that wavelengths of 500 to 3000 km will become unstable if sufficient shearing motion is present. For the major perturbations of the upper atmosphere, Charney (1947) predicts that wavelengths of less than 6000 km (equivalent to a half wavelength of 27° latitude) will be unstable if there is sufficient wind shear. The stage 1 graph (Fig. 38) presented here correlates the long half wavelengths of the upper atmosphere waves (designated as stable by Charney) with continuation and subsequent development of a low-level frontal wave. This is not in conflict with either Petterssen's or Charney's hypotheses. Rather, the long half wavelengths of the upper atmosphere waves may be important to the development of Category I frontal waves because they are associated with a high level of nondivergence and a deep divergence layer (Bjerknes, 1944), or the long wavelengths may be pertinent to this solution for other reasons.

In summary, it is concluded that a satisfactory solution to the development of Category I cyclones has been achieved. The forecasting graphs are presented in Figs. 38, 39 and 41. The forecasting utility of the composite graph is obvious. No statistical measures of significance were attempted.

A diagram summarizing the forecasting technique for the development of Category I cyclones is presented on the following page. Also, a sample worksheet is illustrated. The diagram and the worksheet were designed for practical application of the method by the forecaster.

DEVELOPMENT FORECAST FOR CATEGORY I CYCLONES



WORK SHEET FOR FORECASTING DEVELOPMENT OF CATEGORY I CYCLONES

REQUIREMENTS: Sea level cyclone of some stature located under northwest flow at 700 mb with past track from northwest.

Date: Time surface chart .... Time upper air ....

	850	700	
1. Mark on the 850-, 700-, 500-mb charts the location of the sea level low (ignoring the 3-hr time lag between surface and upper air charts)..........			
2. At 850 mb, geostrophic wind speed over the low is	×	24 =	
	....		....
Move up contour over the low center this distance.			
Temperature at this upstream point is	....		
Temperature over low is	....		
Difference (advective term) is			....

At 700 mb, draw line through low center perpendicular to belt of northwest flow and indicate 200-mile intervals for 1000 miles either side of low. Draw this identical axis on the 500-mb chart with the identical 200-mile interval markers. Enter below the temperatures at each interval at both levels:

Southwest	1000	800	600	400	200	low	200	400	600	800	1000	Northeast
500												
700												
Indices												

Subtract the minimum index which must be to the northeast of the low from the maximum index which will be adjacent to the low or to the southwest. This difference is the instability contrast and is ....

With advective term and instability contrast, enter Fig. 38.

Stage 1 value is ....

3. At 700 mb, measure the distance in degrees latitude along an east-west line through the low center from the trough to the east to the ridge line west. This is the half wavelength ....

At 700 mb determine the most northern latitude and the most southern latitude of the contour through the low center, the difference is the amplitude.......... ....

With half wavelength and amplitude values, enter graph, Fig. 39.

Stage 2 value is ....

4. With stage 1 value from 2 above, and stage 2 value from 3 above, enter Fig. 41. Hrs

Development forecast is Filling within ....

Nonfilling ....

VERIFICATION		
	FORECAST	OBSERVED
Speed	....	....
Direction	....	....
Intensity Fill or Nonfill	....	

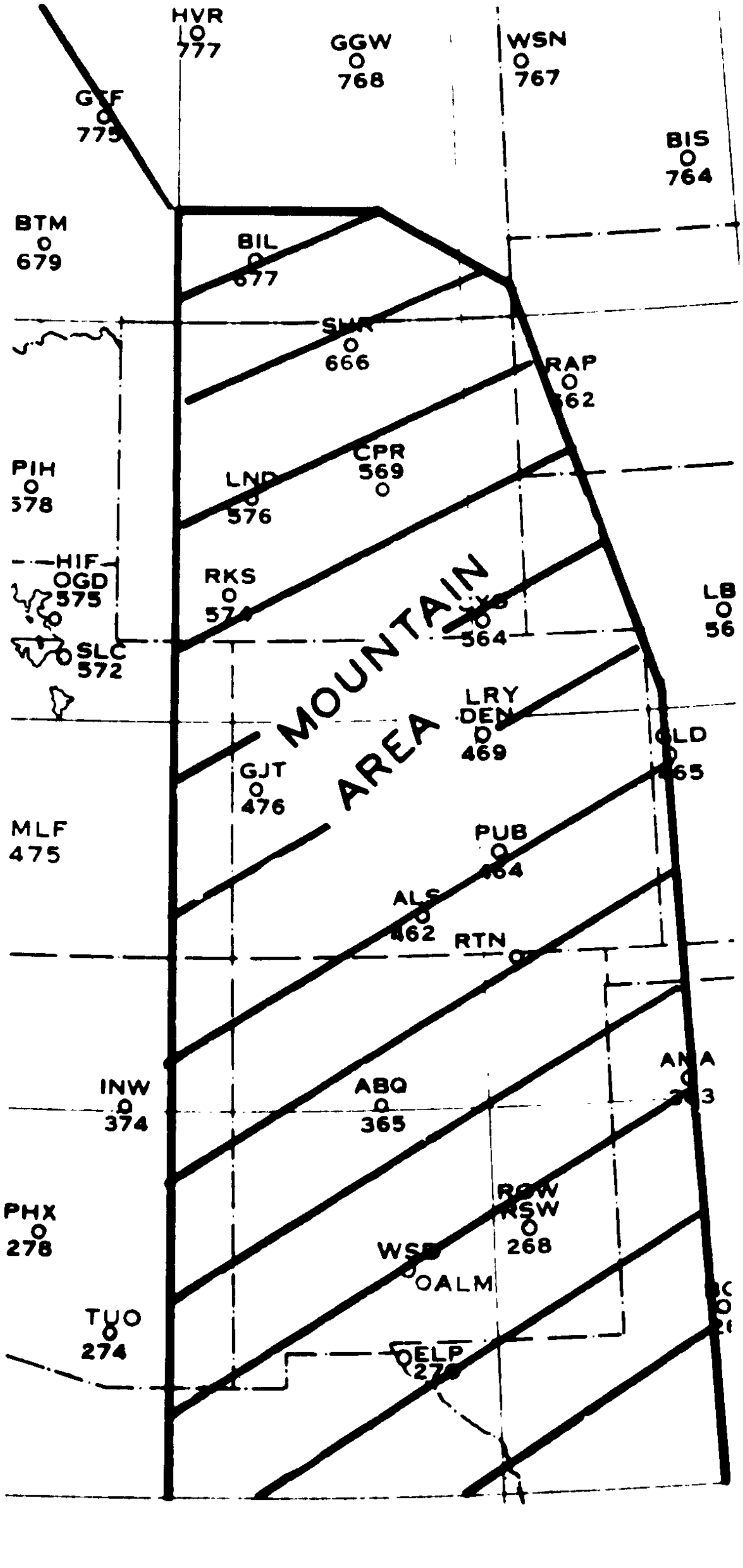


Fig. 42. "Mountain Influence" area. Category I cyclones located in this region move erratically. No movement forecast can be made by Category I techniques.

1.5. MOVEMENT

Category I cyclones generally move southeastward with speeds of 20 to 40 knots. If these cyclones persist long enough, however, they will recurve toward the northeast and thus pose an additional problem in the movement forecast. Because of this recurvature characteristic, Category I cyclones move less uniformly than other types, with deceleration often occurring prior to recurvature. Accordingly, simple extrapolation techniques work poorly. Therefore, the movement forecast requires three elements: speed, direction, and time of recurvature. The speed and direction forecasts are for a period of 24 hours, or until time of recurvature if this is earlier. The forecast of the time of recurvature is the number of hours before the cyclone turns north of east. If recurvature does not occur within 30 hours, the cyclone is called "non-recurving" for that forecast period.

There are two general limitations to the movement forecasts of Category I cyclones. These are geographical and developmental. Lows located in or immediately east of the mountain ranges are erratic in movement to a point of randomness. Accordingly, it is necessary as the first step in the movement forecast to exclude all cyclones which are within 100 miles of the Wyoming-Colorado-New Mexico mountains. This area has been delineated in Fig. 42. The location of each Category I low in the mountain area has already been shown in Fig. 32. The large majority of these cyclones lie outside of the mountain area.

The second general limitation imposed on the movement forecast depends on the development of the celi. Those cyclones which fill rapidly require a different movement forecast from those which persist or deepen. Obviously, a frontal wave filling rapidly is a shallow system, whereas one which is intensifying is likely to affect a deeper layer of the troposphere.

1.51. *Speed*

The forecast of the speed of movement for Category I cyclones is dependent on the persistence of the low.

> *If the cyclone fills in 18 hours or less*, speed prediction is neither possible nor desirable. The cyclones, as they fill, move irregularly. The majority move faster than the 700-mb geostrophic wind over them.
>
> *If the cyclone fills in 24 to 42 hours*, its speed will be approximately that of the 700-mb geostrophic wind over the low for a period of 24 hours, or until the time of recurvature if this is earlier. This relationship is illustrated in Fig. 43.
>
> *If the cyclone persists longer than 42 hours*, the speed of movement of the cyclone is related to the thermal patterns aloft. In general, the greater the thermal gradient in the quadrant northeast of the low center, and the farther the low center lies west of the isotherm trough, the greater will be its speed. The parameters which describe these thermal characteristics are illustrated in Fig. 44. The first is the measurement at 700 mb of the temperature difference between the low center and the coldest air in the northeast quadrant within 1000 miles. The second, also at 700 mb, is the distance in degrees latitude eastward from the low to the center of the cold isotherm trough. These two parameters are correlated in Fig. 45.

The summarized data for the speed of movement of all Category I cases are given in Table 3 of Appendix II.

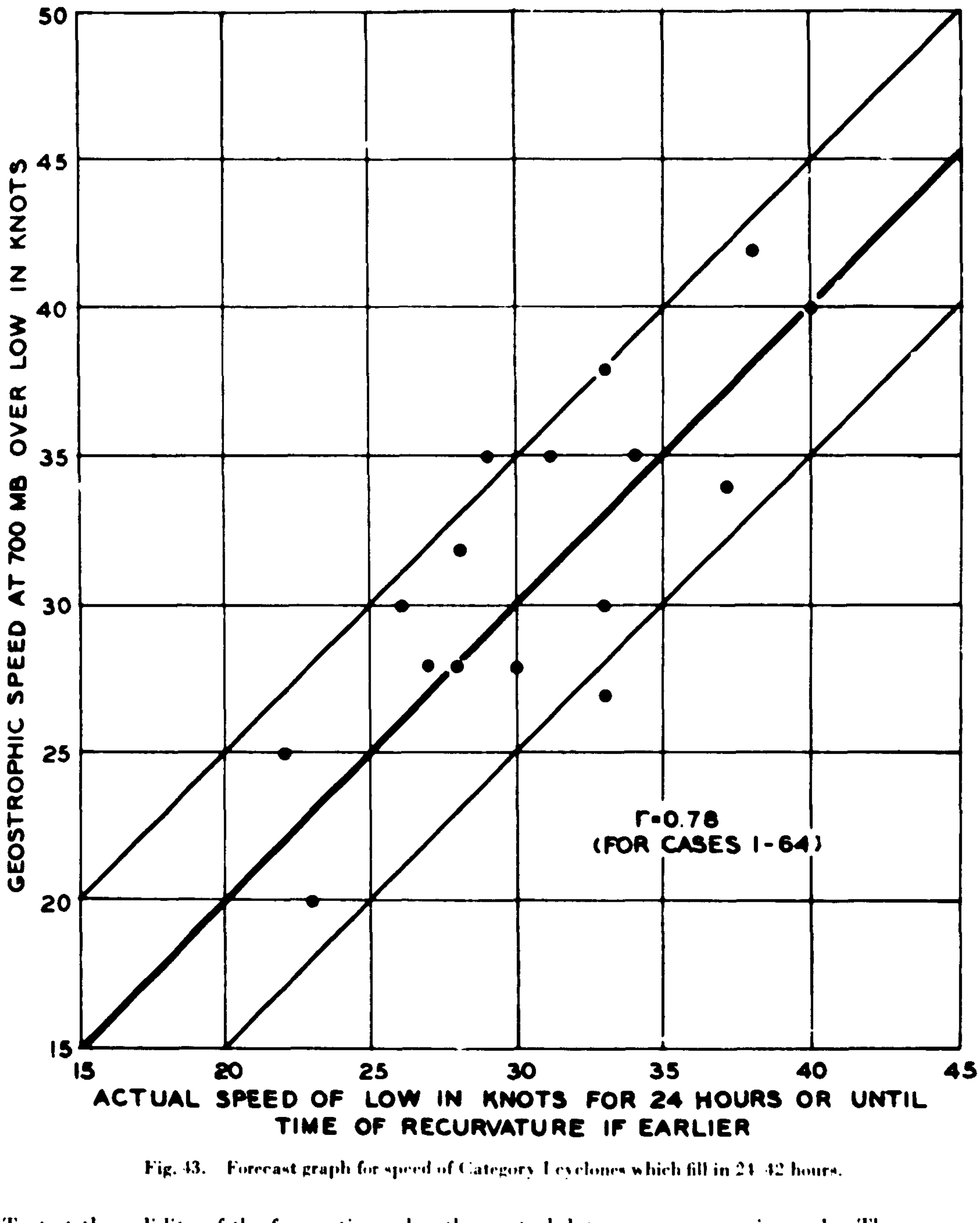


Fig. 43. Forecast graph for speed of Category I cyclones which fill in 24-42 hours.

To test the validity of the forecasting rules, the control data group was again used. There were only two cases of cyclones persisting for 24 to 42 hours, so no conclusions could be drawn for this group. For cyclones persisting longer than 42 hours, it was necessary to utilize the control data in arriving at the solution presented above. When the original data (cases 1 through 64) were analyzed, the use of the 700-mb geostrophic wind over the low provided satisfactory forecasts, with a correlation coefficient of 0.66. When this was tested with the control group (cases 65 through 100), however, the correlation coefficient dropped

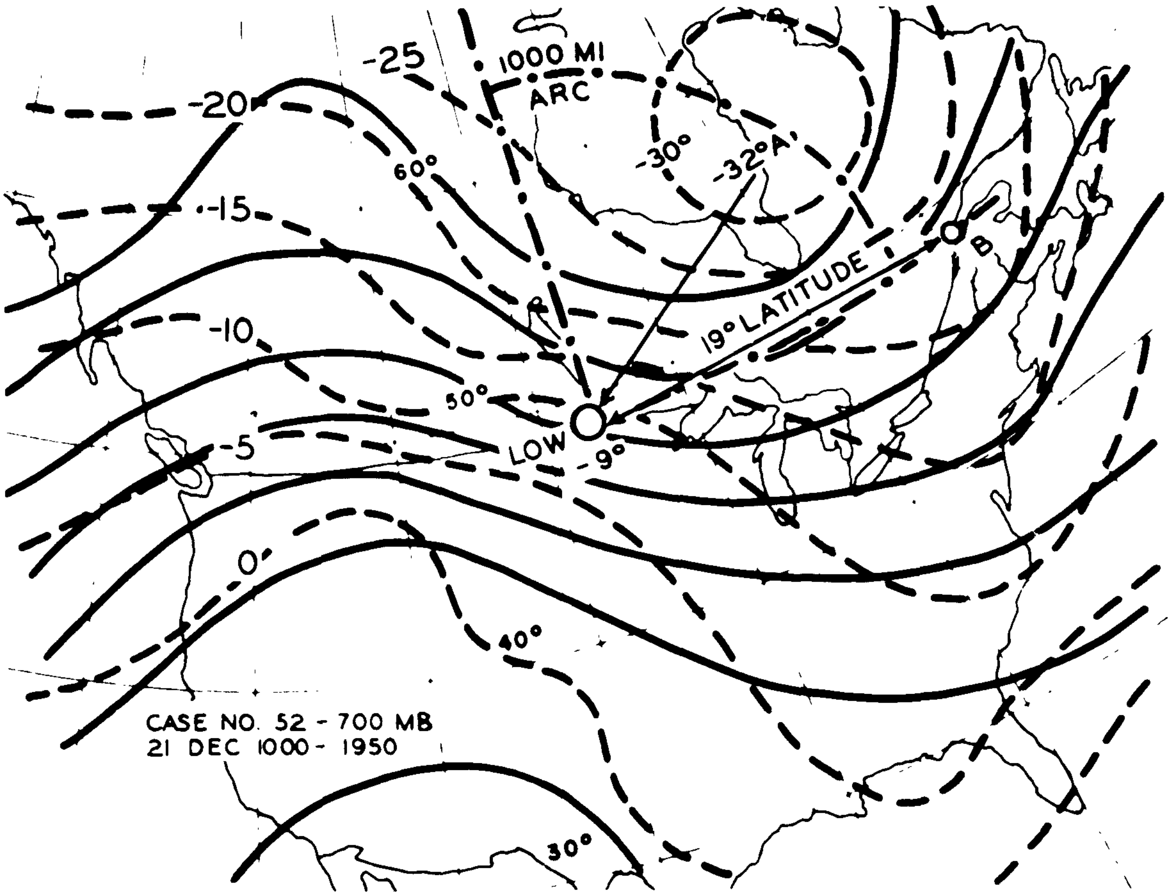


Fig. 44. Speed forecast parameters for nonfilling Category I cyclones. The "Maximum Temperature Difference" is the temperature difference from the low center to point "A", which is the coldest point in the northeast quadrant within 1000 miles of the low center; in this instance, 23°. The "Distance East to the Cold Tongue" is the distance, in degrees of latitude, from the low center to point "B", which is the intersection of the isotherm trough east of the low with the latitude line of the low center; in this instance, 19° of latitude.

to 0.39. Additional study with the total combined data provided the thermal solution described above, producing adequate forecasts for the *entire* sample, with a correlation coefficient of 0.84. Obviously, a test using a new independent sample is desirable. Appendix III lists the complete information for the control data group.

1.52. *Direction of Movement*

Category I cyclones steer with the 700-mb flow reasonably well. In this study, "steering" is defined as follows: when the general character of the contours over the low is straight or anticyclonically curved, steering is motion in the direction of the local flow over the center at 700 mb; when the contour pattern is cyclonically curved, steering is defined as motion downstream along the contour at 700 mb over the low center (which involves a deviation to the left from the "local" steering criterion). The steering definitions are illustrated in Figs. 46 and 47; contour steering is more common than the local type.

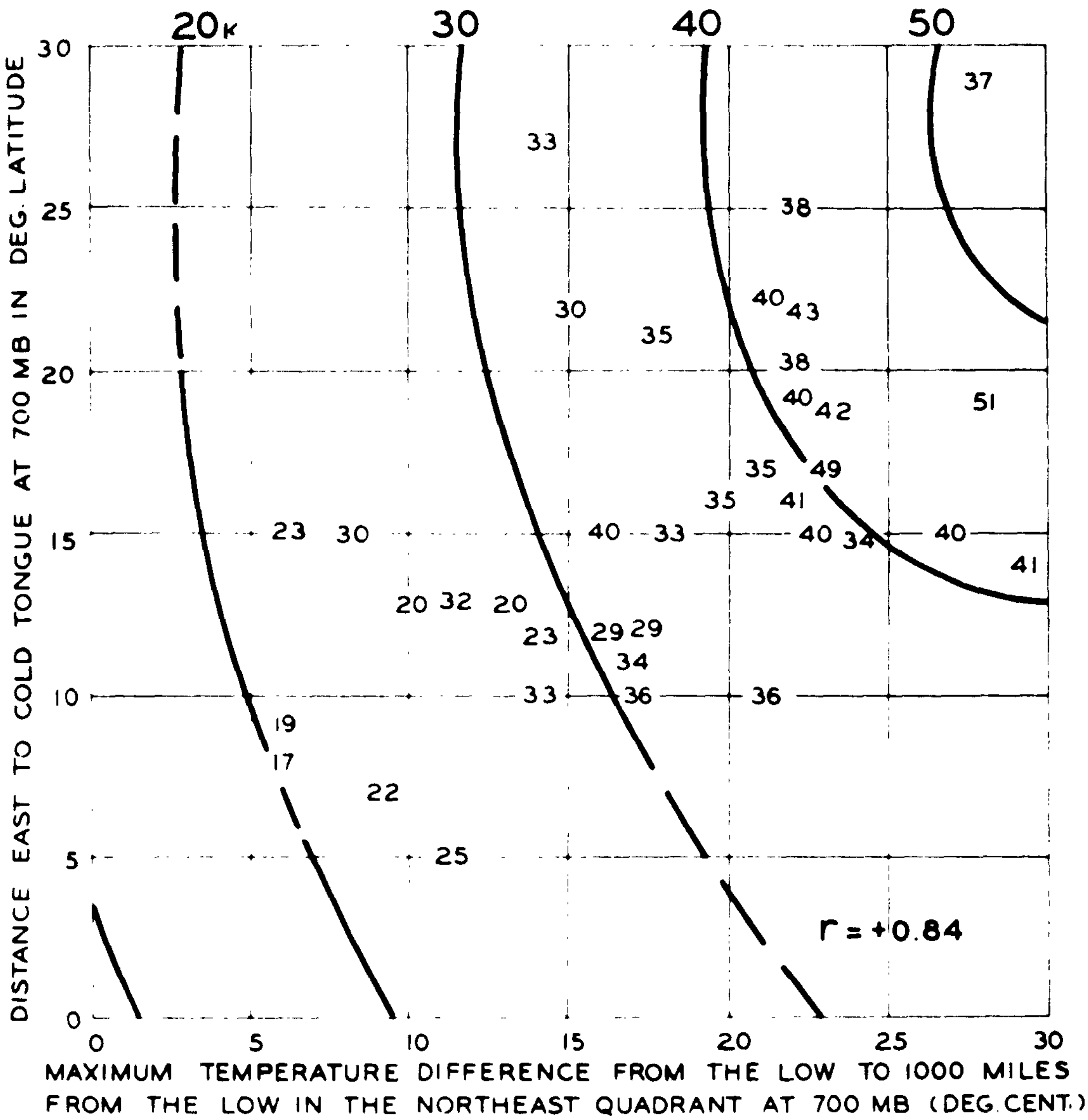


Fig. 15. Forecast graph for speed of nonfilling Category I cyclones. The curves represent forecast speeds and the numbers are actual speeds, both in knots for 24 hours or until the time of recurvature. See Fig. 14.

The development of the low cell is also important in forecasting the direction of motion.

If the cyclone fills in 18 hours or less, it will move erratically; the majority deviate to the right of the steering current, often as much as 20°. The probability of marked right deviation is greatly increased if the cyclone has originated by forming in the southern end of a north-south trough (see Section 1.34).

If the cyclone persists longer than 18 hours, the forecaster should assume reasonable steering, as defined above, for 24 hours, or until the time of recurvature, if this is earlier.

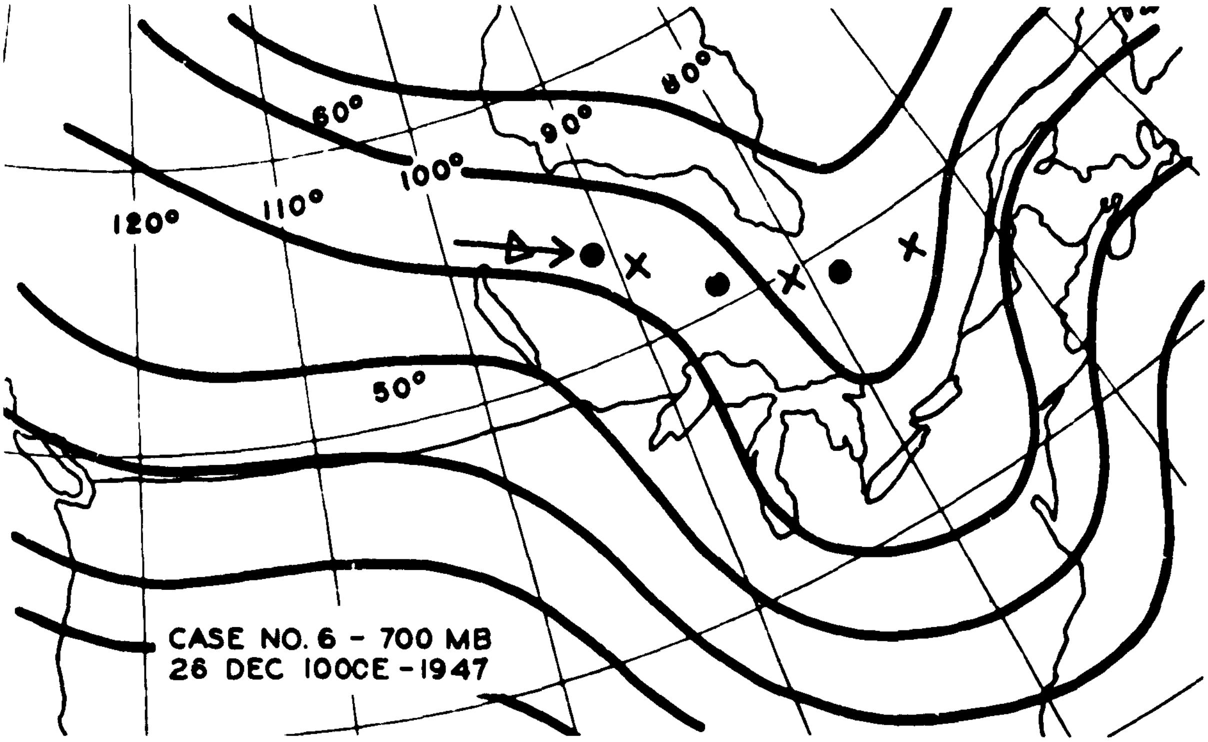


Fig. 46. "Local" steering defined for anticyclonically curved or straight contours downstream from the low. The local direction of flow above the low at 700 mb is shown by the arrow, with the track of the low prior to recurvature.

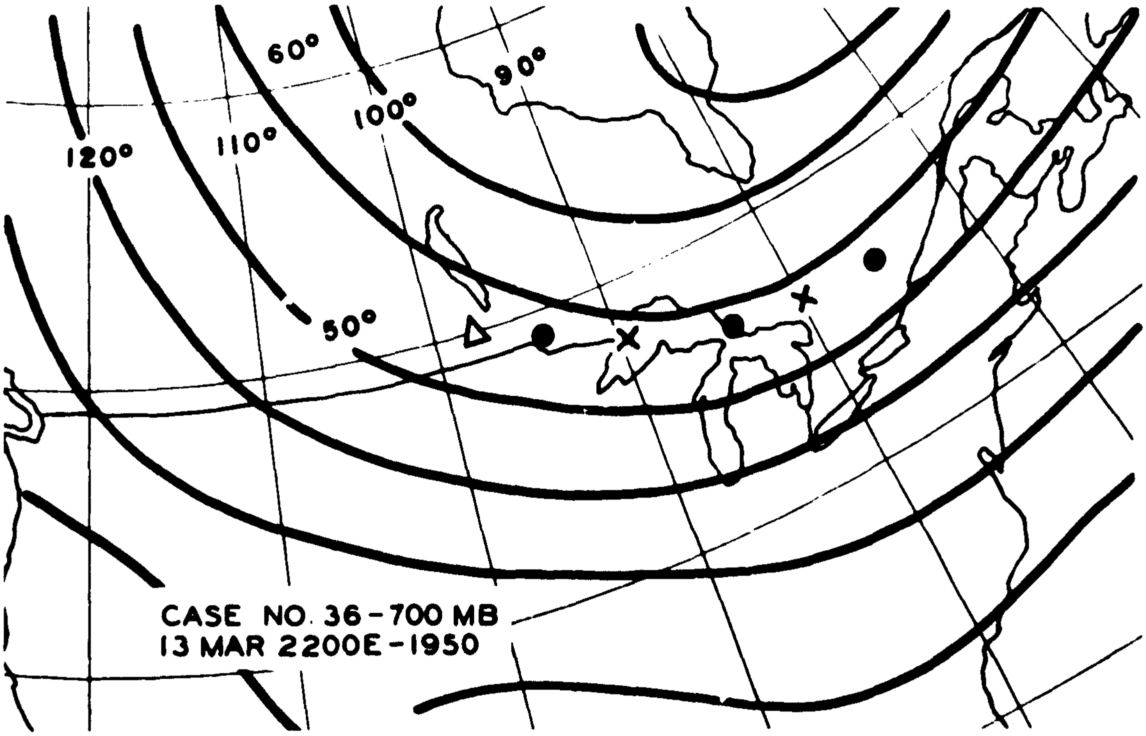


Fig. 47. The more common type of "contour" or channel steering defined for contours curved cyclonically downstream from the low. The track of the low follows the contour channel prior to recurvature.

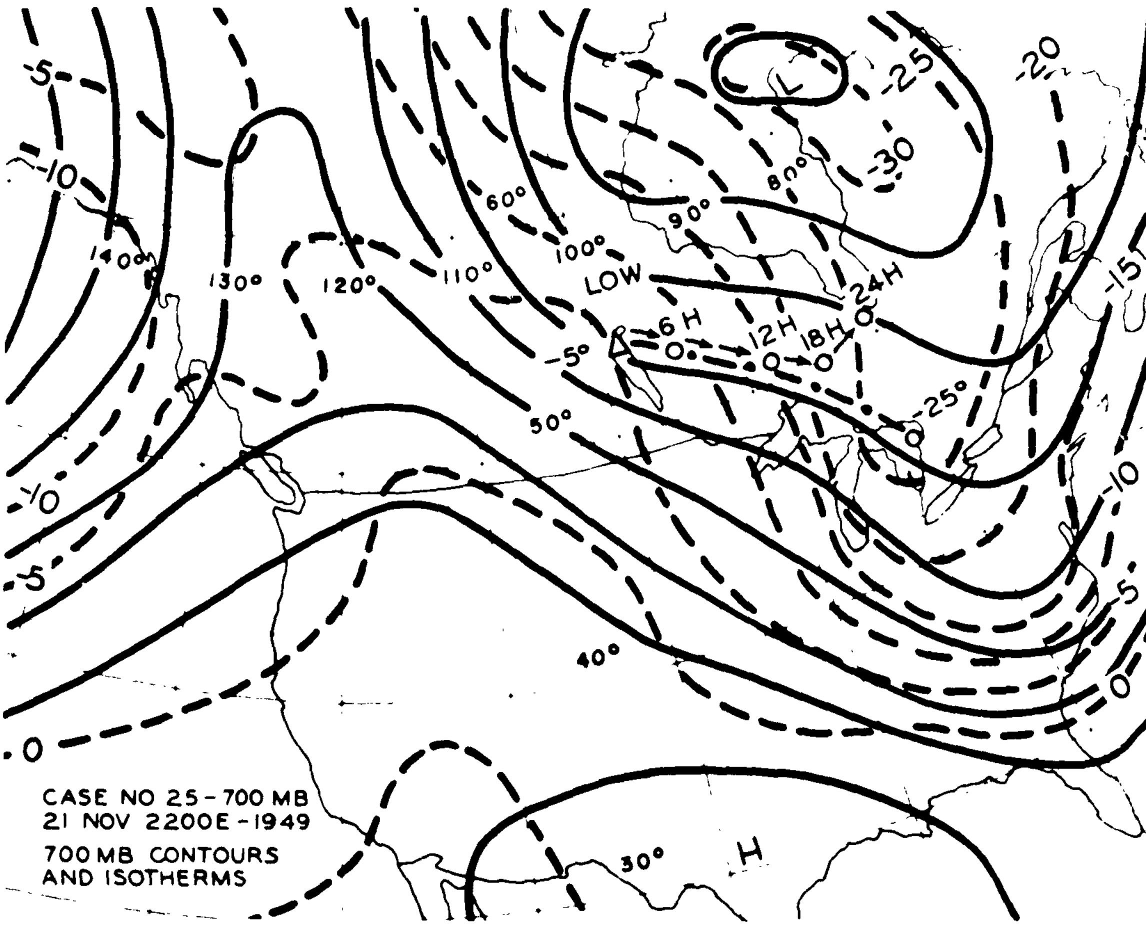


Fig. 48. Recurvature forecast parameters for Category I cyclones. The 700-mb "Temperature Over the Low" is −5 C. Moving downstream along the contour over the low (the path is shown by the dashed line), the coldest air from the low to the downstream trough is −25 C. The "Temperature Difference Downstream" is 20 C. Note the well-defined isotherm crest over the low and the hint of a perturbation just starting to form. The actual track of the low (shown by arrows) is an example of "18-hour" recurvature.

Unless filling or recurvature intervened, deviation from steering was measured for the 24-hour position. The following chart illustrates the reliability of the steering parameter.

	Lows Persisting 24 Hours or More			Lows Filling in 12 or 18 Hours		
	Original Data	Control Data	Total	Original Data	Control Data	Total
Steered within 10°	33	10	43	5		5
Deviated to right 10°–40°	8	3	11	6	2	8
Deviated to left 10°–30°	2	1	3	1	–	1
Total	43	14	57	12	2	14

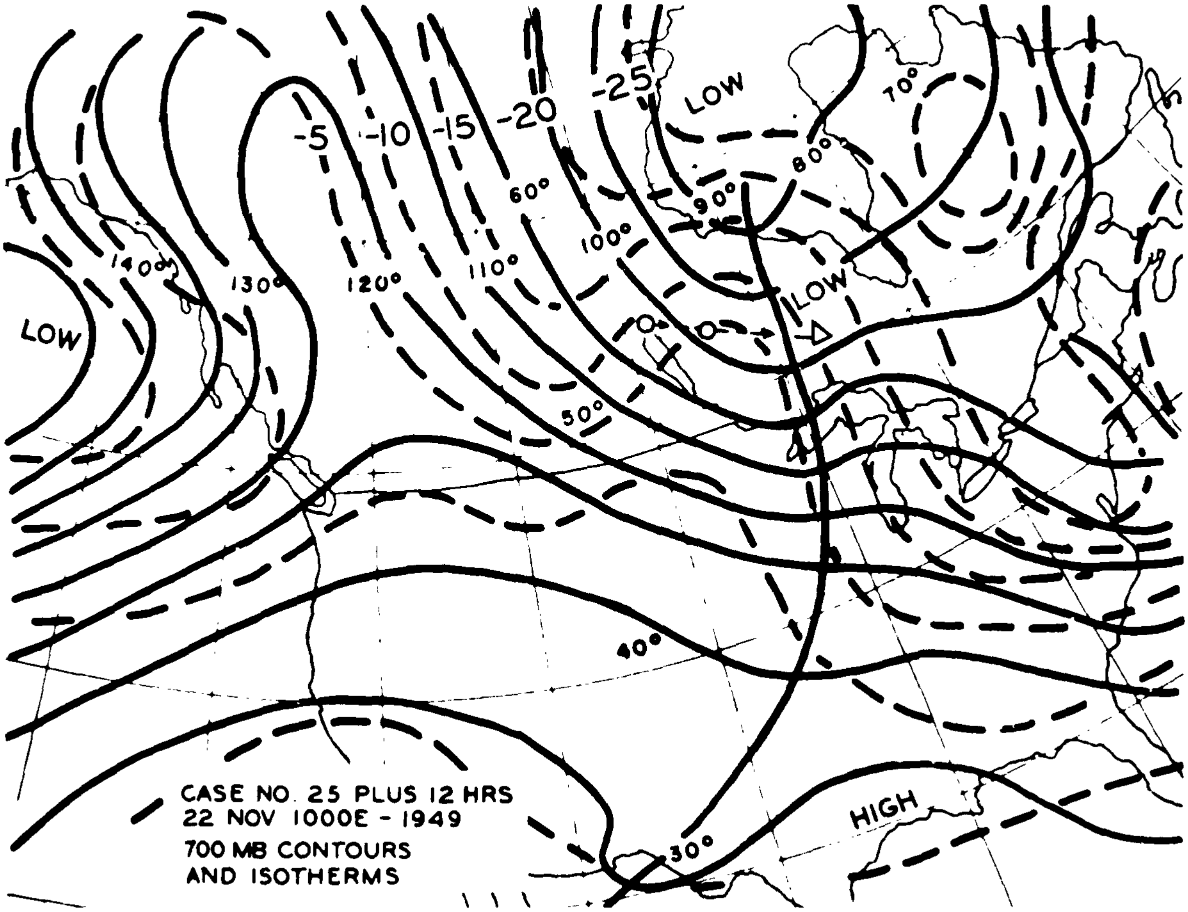


Fig. 19. Recurving cyclone 6 hours before recurvature. The map above, 12 hours after Fig. 18, illustrates the crest-perturbation-recurvature sequence. The cyclone is now nearly in Category II, lying just to the east of a pronounced perturbation, and recurves within 6 hours.

Table 3 of Appendix II provides the necessary data for direction of movement of Category I cyclones. The control group data, given in Appendix III, validate these direction-forecast rules.

1.53. *Time of Recurvature*

This is defined as the time in hours before the cyclone begins to move north of east; or, in cases of cyclones with a track from north of 330°, the time before the cyclone moves due east, or north of east. In analyzing the data, some difficulty is experienced in determining the exact time of recurvature in cases of shallow recurvature angles; but this is infrequent.

To forecast the time of recurvature, thermal considerations are again necessary. George (1949) introduced the idea of a thermal "crest" in determining the time and place of recurvature of a certain class of cyclones with considerable success. Recurvature of Category I cyclones is usually associated with the formation of a new trough or perturbation west of the sea-level low position. Apparently a prerequisite for the formation of this trough is an isotherm crest imbedded in the northwest flow over the sea-level cyclone. Figure 18 shows this pattern at the 700-mb level. Note the well-defined thermal crest in the vicinity of the low (the magnitude of the crest is best seen when viewed along the contours, rather than an east-west line of sight). Figure 19 depicts the same case 12 hours later, and illustrates the typical rapid

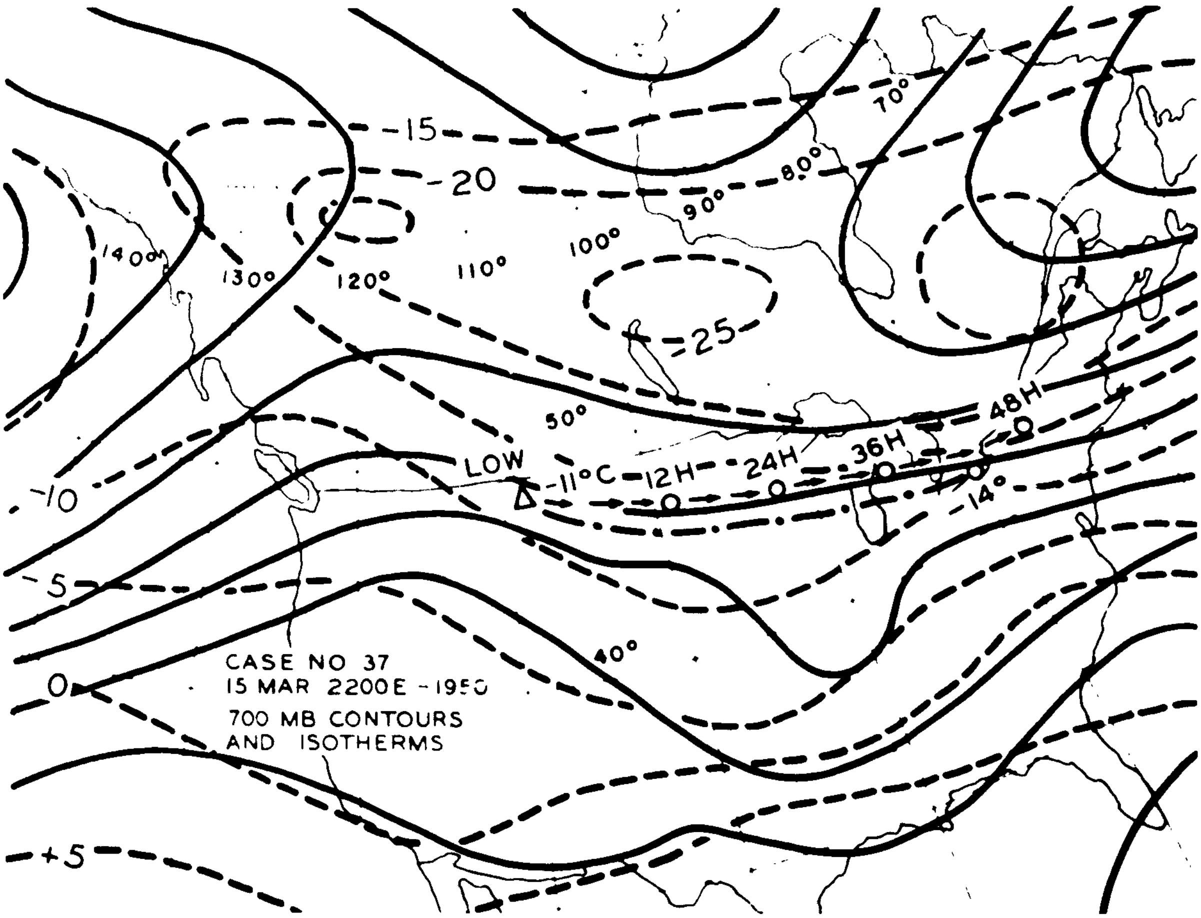


Fig. 50. A non-recurving Category I cyclone. In contrast to Fig. 48, note the complete absence of an "isotherm crest" over the low. The actual track of the low, shown by arrows, illustrates "channel" steering, without recurvature, for at least 30 hours. The recurvature-forecast parameters are: "Temperature Over the Low," − 11 C; and "Temperature Difference Downstream," 3 C, (the coldest air downstream along the contour is − 14 C). Figures 51 and 52 illustrate the contribution of these two parameters to a non-recurvature forecast.

development of a perturbation which usually follows the occurrence of a thermal-crest pattern. Within a short time after trough formation, the cyclone recurves north of east. Figure 50 illustrates the 700-mb pattern for a Category I low not associated with a thermal crest. This pattern is not conducive to trough formation and is therefore associated with nonrecurving lows. It is not evident from the data that the order of events — i.e., crest, perturbation, recurvature — is always followed; however, an empirical relationship between two thermal-crest characteristics and subsequent recurvature was found to have forecasting significance.

The two parameters which define characteristics of the 700-mb isotherm crest, and which apparently measure its effectiveness in producing recurvature are the actual temperature over the low and the difference between this temperature and the coldest air found downstream along the contour over the low. The measurement of these factors is shown in Figs. 48 and 50. These two parameters are combined in a single graph (Fig. 51) upon which has been superimposed a family of curves, labeled stage 3.

With an isotherm crest of given effectiveness — i.e., a specific stage 3 value — the time lag before recurvature depends also on the character of the wave pattern in which the crest is embedded. This feature can be measured by utilizing the stage 2 value from the development forecast (see pp. 59 and 62 and Fig. 39), in which half wavelength and amplitude measurements are combined. The composite graph correlating stage 2 with stage 3 is presented in Fig. 52; this diagram specifies the number of hours until recurvature (up to 30 hours). Table 3 of Appendix II presents the data relative to this recurvature problem for all Category I cyclones.

The control group of data was again analyzed for recurvature features in order to test the validity of this forecasting device. The results were satisfactory, although no measurement of statistical significance was derived. Appendix III presents the pertinent control group data. A diagram summarizing the complete movement forecasting for Category I cyclones is shown on page 78. A sample work sheet for practical application of the method by the forecaster is also given.

FOR FIGS. 51 AND 52

OPEN CIRCLES O ARE RECURVING CYCLONES; NUMERALS ARE TIMES OF RECURVATURE.
FILLED CIRCLES ● ARE CYCLONES WHICH DID NOT RECURVE IN 30 HOURS OR LESS.
SEE TEXT, P. 69 FOR DEFINITION OF STEERING.

CASES WHICH FILLED PRIOR TO FORECAST RECURVE TIME, OR WITHIN 6 HOURS THEREOF, ARE NOT PLOTTED ON FIG. 52. THESE CASES ARE LISTED BELOW:

CASE NO.	TIME OF FILLING	FORECAST RECURVE TIME	STAGE 3/ STAGE 2
8	18 HR	24 HR	4.7 / 4.2
14	24	(30)	4.2 / M
20	30	24	5.4 / 2.1
21	12	24	5.3 / 2.1
23	18	18	7.0 / 3.0
29	18	30	4.2 / 0.0
30	24	30	4.6 / 3.3
34	18	30	4.5 / 1.1
45	30	24	5.5 / 2.1
67	18	24	5.8 / 2.7
71	6	30	3.7 / 4.3

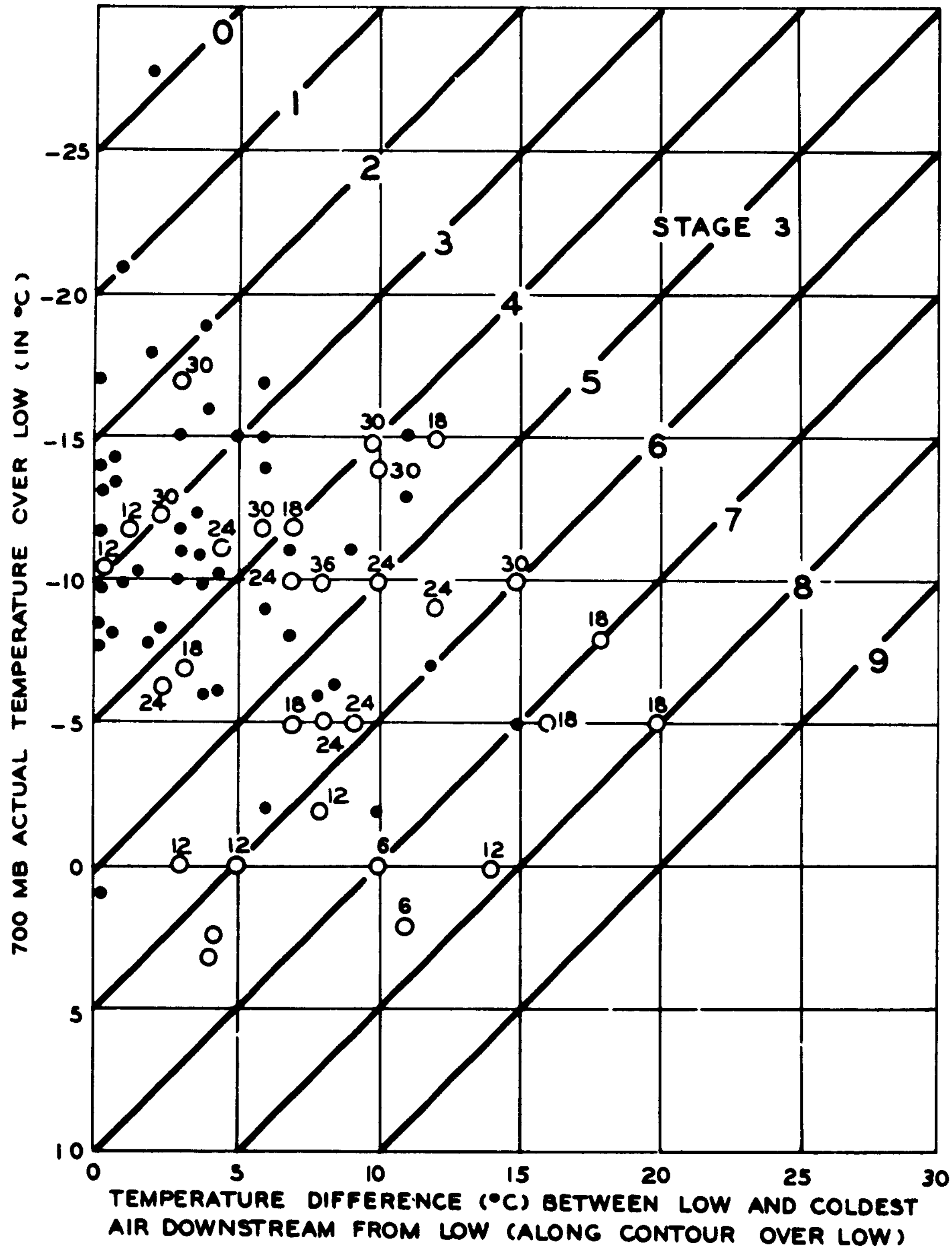


Fig. 51. Forecast graph for recurvature of Category I cyclones. Use of this graph is the first step in a recurvature forecast. The family of curves provide stage 3 values, which are utilized in Fig. 52, the final forecast graph.

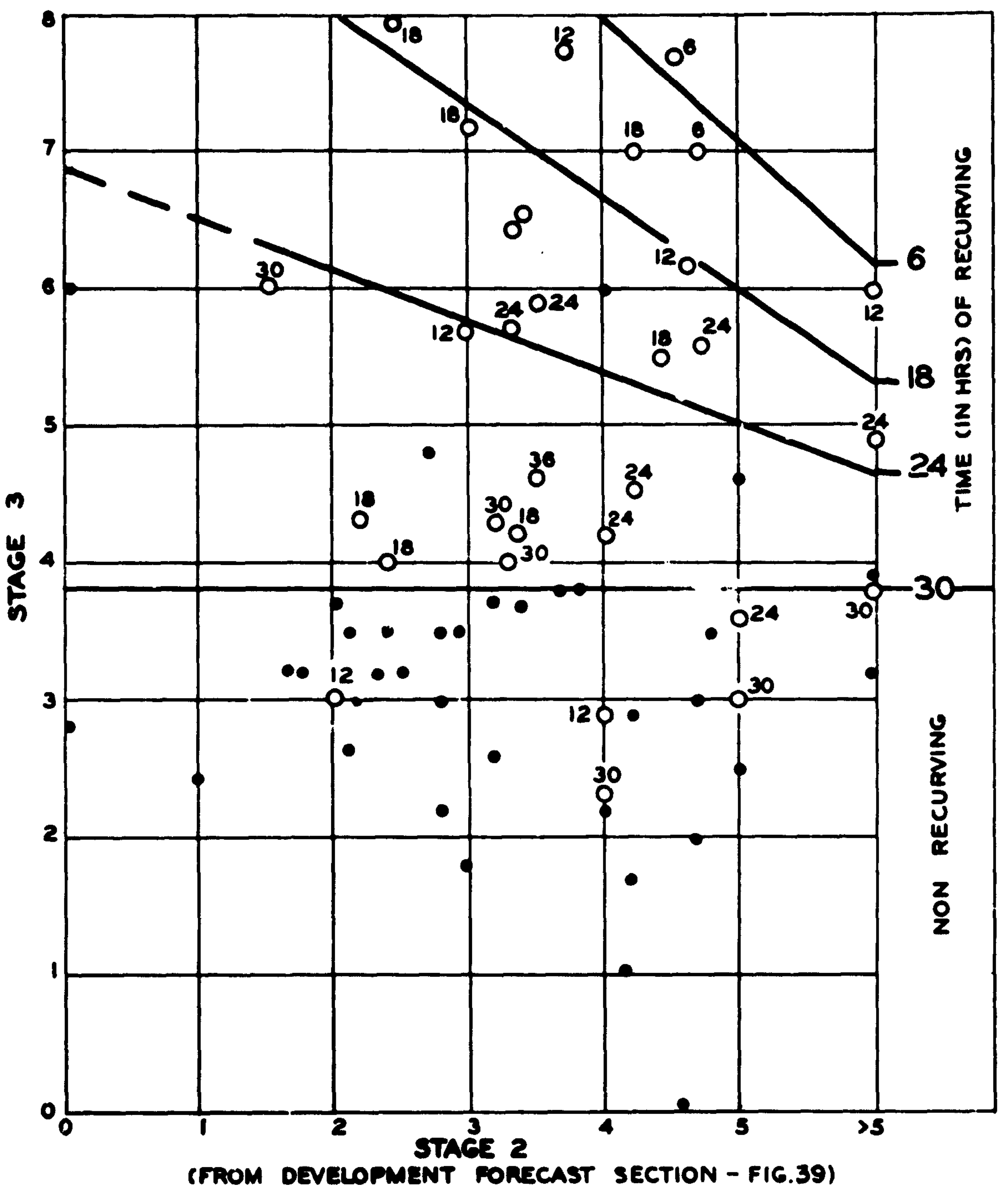
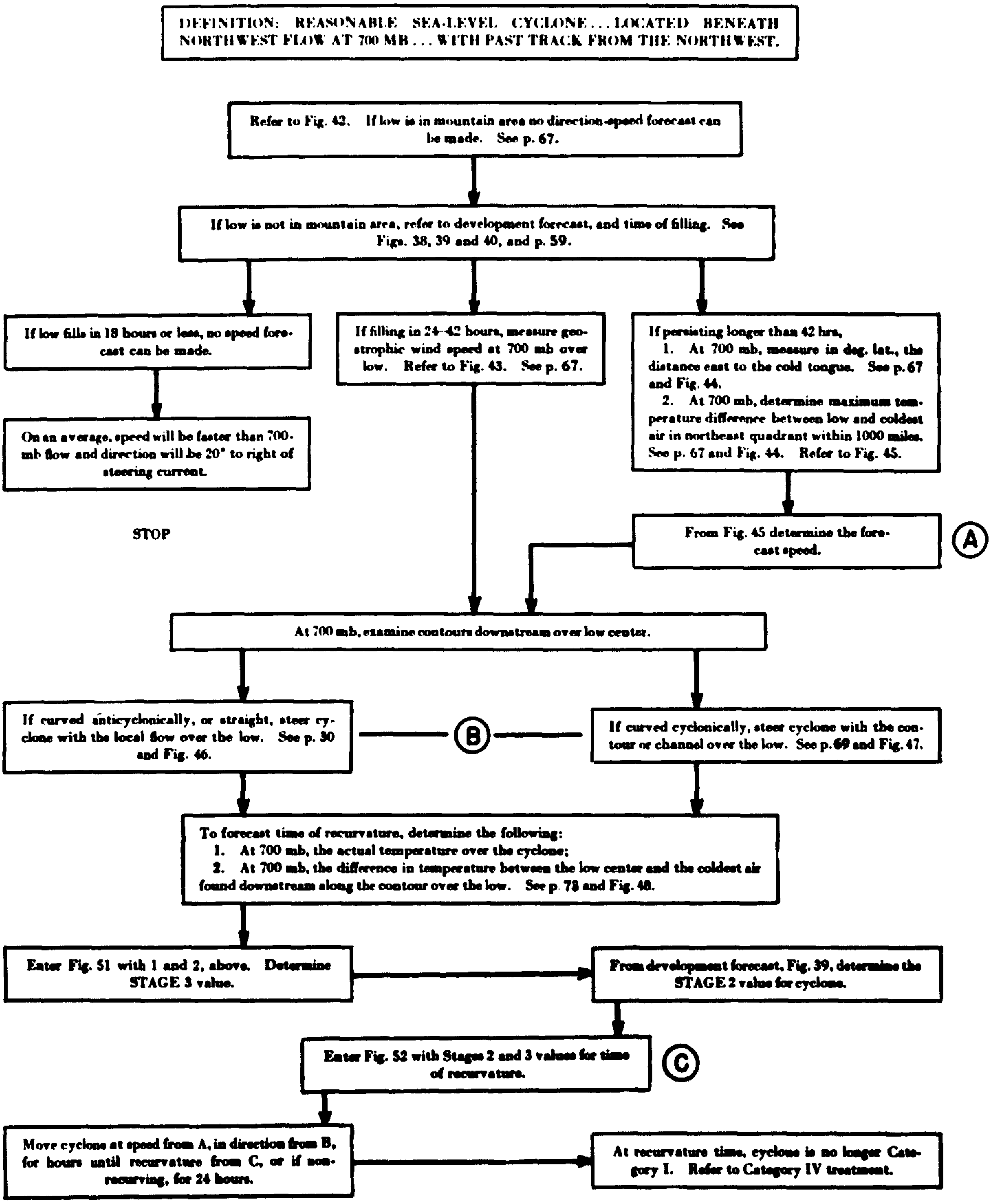


Fig. 52. The final forecast graph for the recurvature of Category I cyclones. To forecast the time of recurvature, enter the stage 3 values from Fig. 51 and the stage 2 values from Fig. 39 (of the development section). The resultant forecast is the number of hours until recurvature. (Recurvature occurs when the cyclone turns north of east.)

MOVEMENT FORECAST FOR CATEGORY I CYCLONES



WORK SHEET FOR FORECASTING MOVEMENT OF CATEGORY I CYCLONES

Date .... Time Surface Chart .... Time Upper Air ....

700

1. Refer to Fig. 42. If sea-level cyclone is located in mountain area, no direction-speed forecast can be made by this method. If low is not in mountains, determine from Figs. 38, 39, and 41 development forecast.

   Fill within .... Hrs

   Nonfilling ....

2. If low is forecast to fill within 18 hrs or less, no movement forecast can be made. On an average, speed will be greater than 700-mb flow, and direction to right of steering current at 700 mb.

   700-mb geostrophic wind speed ....

   Forecast speed ....

3. If cyclone will fill within 24–42 hrs, speed will be approximately that of the 700-mb geostrophic wind speed over the low. See Fig. 43 for speed forecast. ....

   If cyclone will persist longer than 42 hrs, at 700 mb, measure distance in degrees latitude east to the cold tongue (thermal trough) .... ° Latitude

   At 700 mb, determine temperature over low and coldest temperature within 1000 miles in northeast quadrant from low.

   Temperature over low ....

   Coldest temperature to northeast ....

   Maximum temperature difference is ....

   With distance east to cold tongue and maximum temperature difference, enter Fig. 45. Forecast speed of low is ....

4. For all cyclones persisting 24 hrs or longer, to forecast direction, examine 700-mb contours over low. If it curves anticyclonically downstream, or straight, move with local flow immediately over low ....

   If contours curve cyclonically (even slightly), steer within the contour channel over low ....

5. For all cyclones persisting 24 hrs or longer, to forecast time of recurvature, determine on 700 mb the temperature over the low ....

   At 700 mb, locate the coldest air found by moving downstream along the contour over the low (not crossing the trough). Coldest downstream temperature is ....

   700-mb temperature minus coldest downstream temperature is ....

   With 700-mb temperature over low and temperature difference downstream, enter Fig. 51. Stage 3 value is ....

   Refer to development forecast, and note value used there for stage 2. See Fig. 39. ....

   With stage 3 value and stage 2 value, enter Fig. 52 time of recurvature is ....

6. Move the Category I cyclone with the speed from 3 above, in the direction indicated from 4 above, for the number of hours until recurvature from 5 above, or if non-recurving for 24 hrs ....

   Forecast position of low ....

   At time ....

2. CATEGORY II CYCLONES

2.1. INTRODUCTION

Category II cyclones are defined as cyclones with a past track from the northwest quadrant and located under southwest flow at 700 mb, but the flow is produced by a minor perturbation in a basically northwest flow pattern. An example of this type of low can be seen in Fig. 49.

The distinction between a mere perturbation and major trough at 700 mb is easily made subjectively. However, an objective method for determining whether a cyclone fits Category II is as follows:

1. At 700 mb, locate the surface position of the low and the associated trough that is producing the southwest flow.

2. From the latitude of the low, measure in degrees latitude the amplitudes of the contour through the low at the major ridge to the west (α_w) and the minor ridge to the east (α_e). Also measure the latitude difference of this contour from the minor ridge to the major trough further east (α_f). These amplitude measurements are illustrated in Fig. 1(*b*).

When α_e is less than *both* α_w and α_f, then the case is assigned to Category II; however, if α_e is greater than 10 degrees latitude, then the trough is major regardless of other considerations, and the case is assigned to Category III. These lows are not essentially different from Category I cyclones, and forecasting techniques are nearly identical. Separate treatment is accorded them for reasons of clarity and continuity. In sharp contrast to Category I lows, these cyclones are prone to be nonfilling; cases where filling occurred in less than 24 hours are rare. Category II cyclones are found in the same general area as Category I cyclones. Category II cyclones were less frequent than Category I, occurring less than once per month in the winter season.

2.2. DATA

Appendix IV presents the data for the Category II cyclones that were studied, employing the same data sample used for Category I cyclones.

2.3. ORIGIN

The pattern of origination is not definitive because of the small sample of Category II lows, however, some statements are pertinent. Numerous Category II cyclones originated as Category I lows under northwest flow. Some of these are included in the Category I data sample; others, for analytical reasons, could not be handled until they fell into Category II, though the origin was obvious. Some cyclones originated as Category II; the first appearance of the surface low was beneath a perturbation at 700 mb.

A Category II cyclone can sometimes develop from a Category III pattern. In this instance, the amplitude measurements which defined the trough as a major system are altered by intensification of the western ridge aloft. The resulting trough becomes a perturbation and the cyclone is classified as Category II.

2.4. DEVELOPMENT OF CATEGORY II CYCLONES

It would be expected that Category II cyclones would develop similarly to those of Category I because of the basic similarity of the upper-air patterns. This was found to be the case.

2.41. *Instability Contrast Parameter* (See Section 1.4, p. 56)

In applying the concept of instability contrast to the Category II cyclone, only one change from the Category I technique was necessary, and that was the orientation of the instability index axis. By inference, Category II axes should be aligned perpendicular to the basic northwest flow pattern which has been disturbed. In practice, this is difficult, especially in those cases with a broad shallow perturbation. A technique which accomplishes almost the same end is to align the axis perpendicular to the past track of the low. The instability contrast parameter is not overly sensitive to small changes in axis alignment, nor to minor temperature variations. This axis orientation produced acceptable results.

2.42. *850-mb Temperature Advective Term* (See Section 1.4, p. 59)

This factor in development is used in the same manner as for Category I cyclones. Generally, the 850-mb patterns present a more accentuated trough system with the low and a greater temperature gradient than a Category I cyclone. Consequently, the advective term is more important in Category II cases. The *average* advective term for Category I lows was $-1°$; it is slightly greater than $-5°$ for Category II cyclones.

2.43. *Half Wavelength and Amplitude* (See Section 1.4, p. 56)

The measurements for half wavelength and amplitude are made in the same manner as for Category I cyclones. The measurements are for the basic macrocirculation pattern, completely ignoring the small area of southwest flow due to the perturbation. It would be expected that Category II cyclones would occur with longer wavelengths than Category I cyclones, since the presence of a perturbation in the northwest flow to a great extent predicates a longer wavelength. This was found to be true; *average* half wavelength for Category I was 33° latitude; for Category II cyclones, 42°. The amplitude relationship between the categories is not so obvious, with only a difference of 5° between average amplitudes.

In summary, the technique for handling Category II cyclones is similar to that for handling Category I. The axis at 700 mb for determination of the instability contrast parameter is laid out differently; other than that the parameters are measured and utilized in the same fashion. Individual stage 1-2-composite graphs are not presented. The composite graph, Fig. 41, does include each Category II case, plotted from the original data listed in Appendix IV. The validity of the Category II technique could not be tested on independent data since the control group (see Appendix III) included only two cyclones of this type. For practical application of the forecasting device on development of Category II cyclones, the forecaster is referred to pp. 78 - 79, which presents a schematic diagram of the method and a sample work sheet.

The investigation of the movement of Category I cyclones emphasized that the forecast problem dealt with the specific time-interval during which the cyclone was moving from the northwest; when recurvature occurred, no prediction of movement could be made.

The time of recurvature of Category II cyclones is 0–12 hours (see Appendix IV); almost 50 percent actually recurve in "zero" hours, meaning that the track changes to north of east immediately. For this reason, no forecast can be made of speed or direction. Further, the only feasible recurvature forecast is that *recurvature will occur within the next 12 hours*, (this forecast is made without reference to thermal patterns). Thereafter, the cyclone is handled like those of Category IV and the forecaster is referred to that section of this report.

CATEGORY III CYCLONES

R. D. ROCHE AND H. B. VISSCHER

1.1. INTRODUCTION

The Category III cyclone is one that moves southeast beneath southwest flow at 700 mb due to a major trough at that level. To determine objectively whether or not the trough should be considered as a major entity, it is necessary to consider the amplitudes of the trough-ridge pattern at 700 mb. The objective technique has been presented in Category II Cyclones on page 80. For Category III cyclones, measure the amplitudes α_e, α_w, α_f. If α_e is greater than 10 degrees latitude, the case is Category III; if α_e is greater than either α_w or α_f, the cyclone is also Category III. This category of cyclones is important because the cyclones have a history of movement across the wind flow aloft and a high percentage of prognostic errors are associated with a continuation of this movement. A typical Category III cyclone is shown in Fig. 1(*c*). The initial location of all Category III cyclones has been shown in Fig. 53; it is possible that this type of storm may be indigenous to the region just east of the Rocky Mountains. These cyclones occur less frequently than Category I, only one to two times per month in a winter season.

The forecasting devices for development and movement of Category III cyclones are not comparable in detail nor in accuracy to devices for cyclones of other categories. Though the sea-level systems are generally large and relatively mature, they are often multicentered and lack compactness, and to a large degree this complexity prohibits precise analysis.

1.2. DATA

The sample data was the same as for Categories I and II; Category III cyclones are case numbers 201–239. The same independent data for control purposes were used here, involving cases 240–267. Tables 1 and 2 in Appendix V cover these data.

1.3. ORIGIN

Although the time relationship between the four categories of cyclones has been substantiated, few of the Category III lows can be shown to have passed through the Category I or II periods. This is not surprising, however, since the transition from Category I or II to Category III or IV is usually rapid, and upper air charts 12 hours apart may well miss a stage. The majority of Category III cyclones formed in the mountain-lee area under southwest flow aloft, or moved in from the Canadian Mountain area across the upper air flow; however, the origin is not pertinent to the forecasting devices presented here.

1.4. DEVELOPMENT OF CATEGORY III CYCLONES

Approximately 50 percent of these cyclones do not materially change their intensities within a 30-hour period; 25 percent fill (decrease in intensity) and 25 percent deepen. The development forecast is therefore of lesser importance than for other categories. Figure 54 diagrams the intensity changes for all Category III cases, and indicates the forecast ranges for filling, no-change, and deepening cases; intensity measurements have been made according to the method described on p. 18. The development forecast then concerns predicting an increase in intensity-count of 5 or more (deepening), a change of less than 5 in either

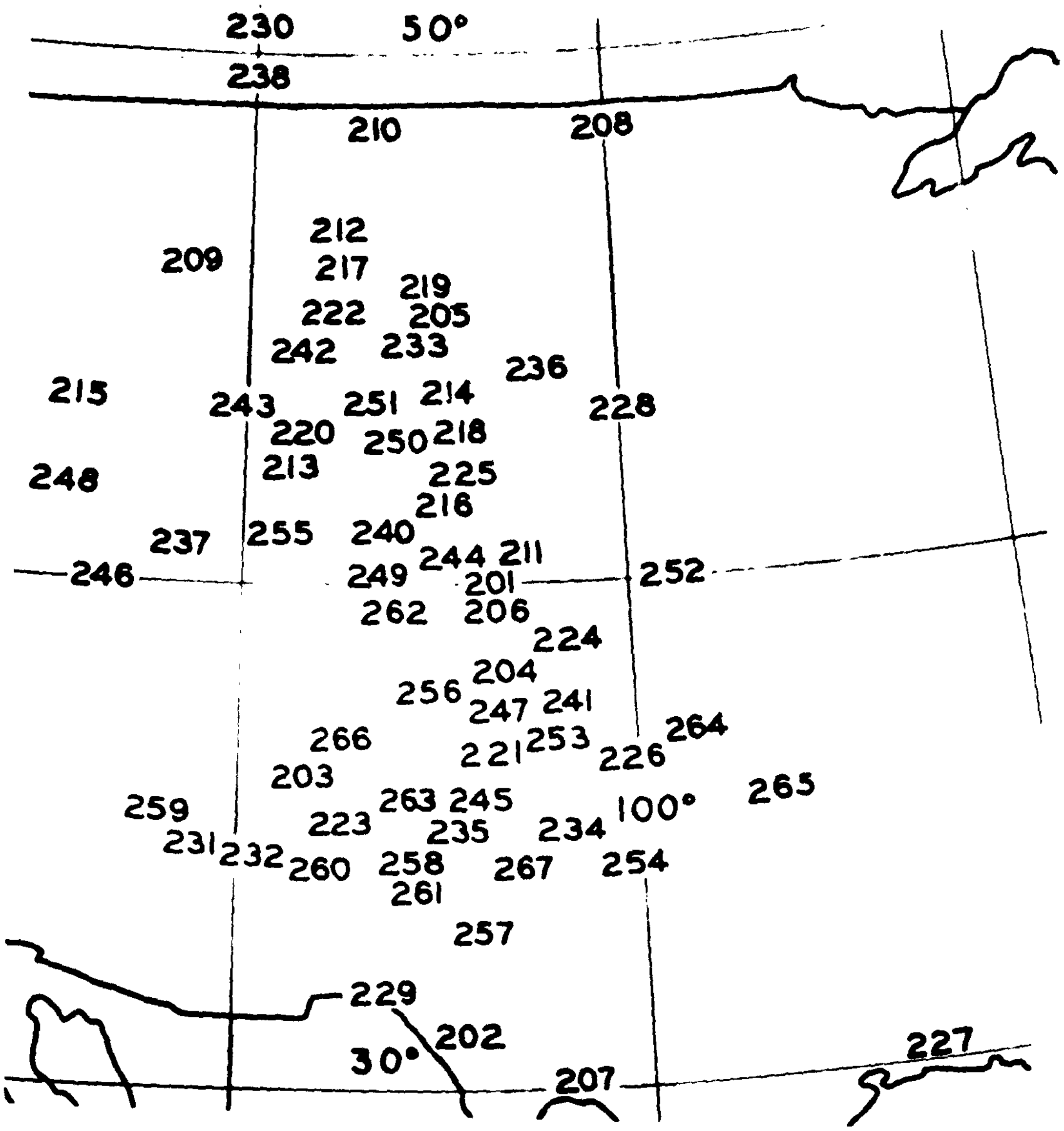


Fig. 53. Location of all Category III cyclones. Numerals indicate case numbers.

direction (no-change), a decrease of greater than 5 but still a closed circulation system (filling), or a decrease of intensity count of greater than 5 with a resulting pressure trough only (filling-to-trough).

A strong indicator of intensity change for Category III cyclones was immediately apparent in the central pressure of the sea-level cyclone: in general, a pressure of 1000 mb or higher was associated with filling to a trough, filling, or no-change; when the central pressure was less than 1000 mb, no-change, or deepening predominated. The arbitrary dividing line of 1000 mb appears to be significant.

With cyclones whose central pressure was higher than 1000 mb, it was found that the location of the trough aloft was a controlling feature of the intensity change, especially in determining whether or not the

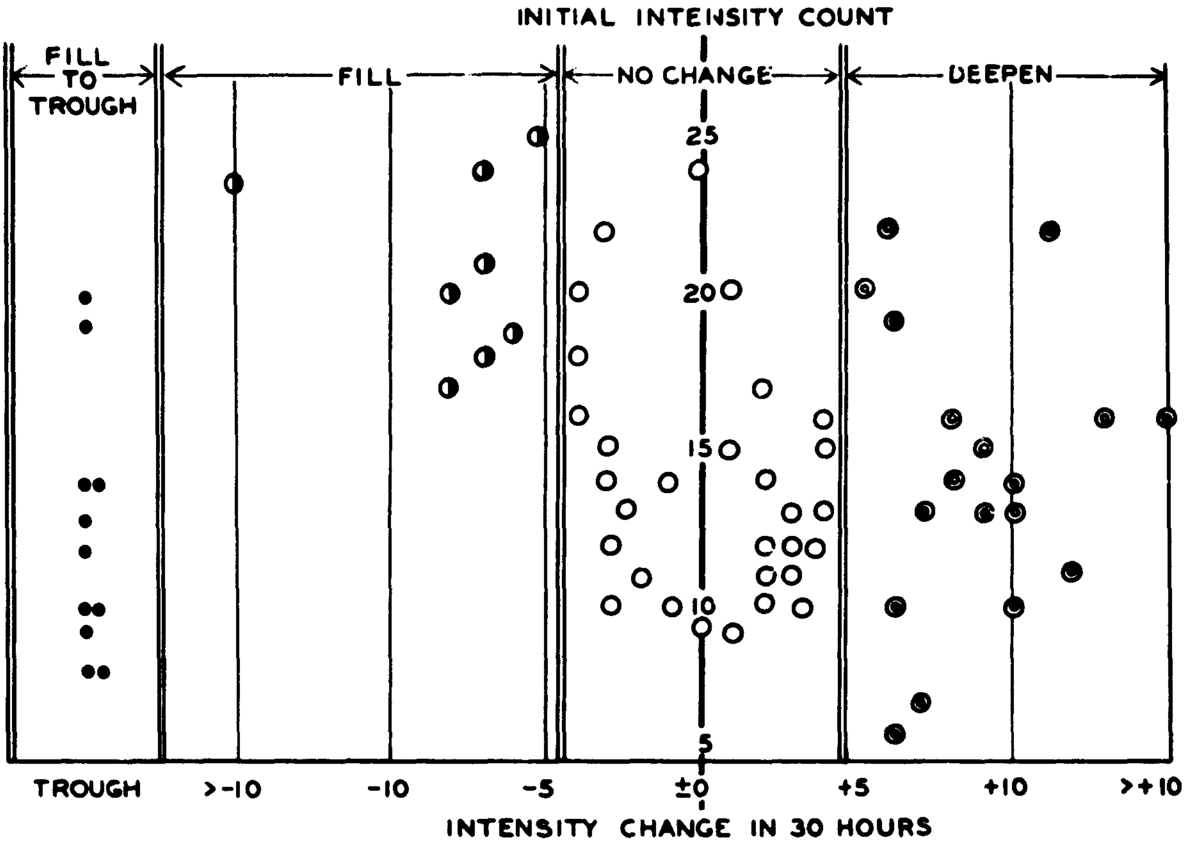


Fig. 54. Intensity changes within 30-hour period for all Category III cyclones. This diagram illustrates the ranges for the development forecast.

cyclone would fill to a trough. With cyclones whose central pressure was less than 1000 mb, the location of the trough aloft was less pertinent. Two other factors indicated the growth or decay of the storm. These were the height of the 500-mb contour over the low and the 700-mb half wavelength.

In attempts to express the central pressure parameter in a more direct component of development, numerous upper air factors were tried. Thermal patterns and contour configurations produced two other possible solutions. Tests on independent data were indeterminate however, and moreover, the results were not superior to the simple technique shown above. Therefore, the following procedure is outlined for forecasting the development of Category III cyclones for a 30-hour period:

1. At the time of classification of the cyclone as Category III, determine the lowest central pressure of the sea level system.

2. If the central pressure is 1000 mb or higher,

   a. Examine the 500-mb chart for the location of a closed system at that level (shown by actual closed contours, or definite easterly winds, or reversal of north-south height profile in that area). If there is a closed cell within 800 miles of the surface low location, *deepening will occur.*

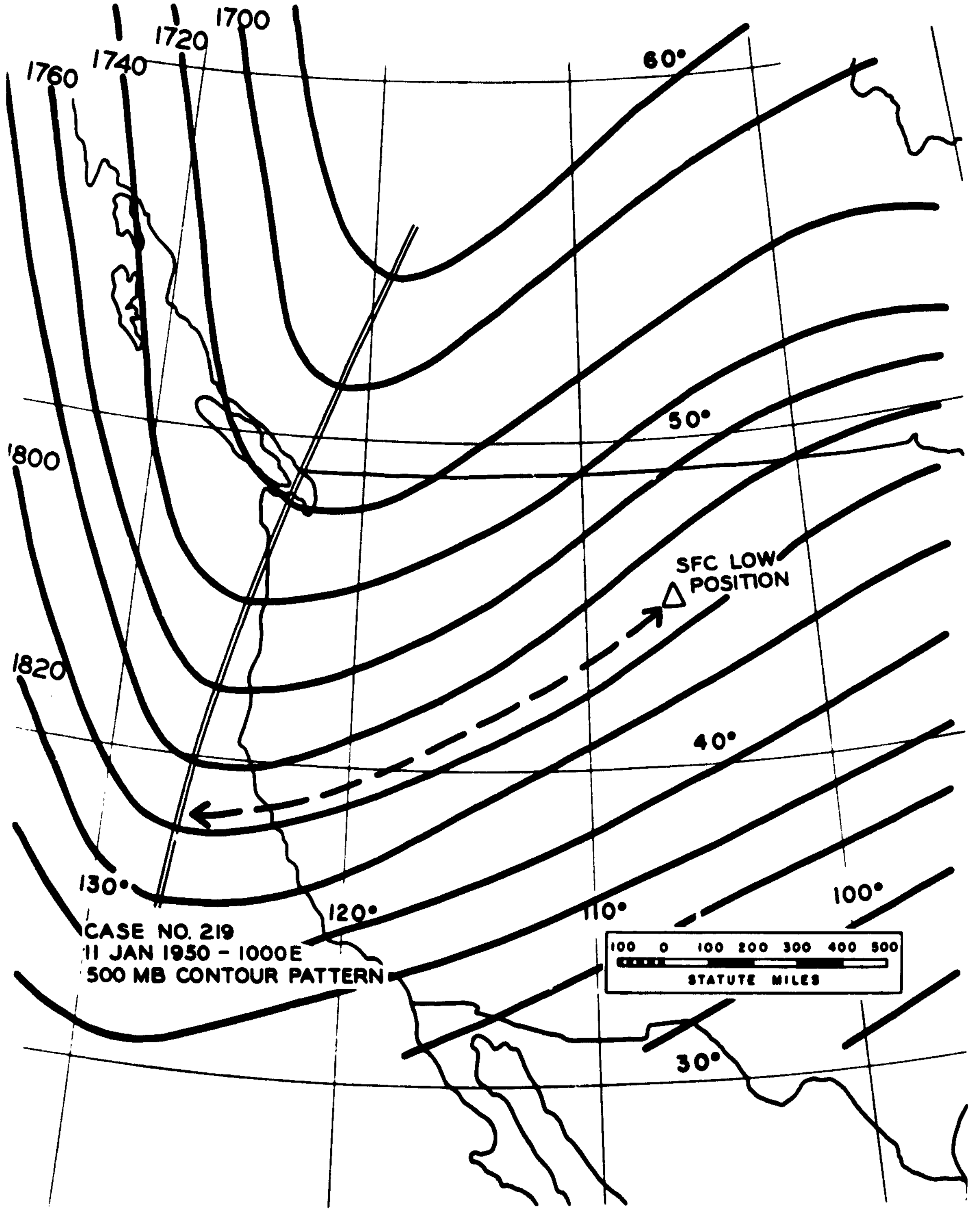


Fig. 55. Measurement of distance up-contour at 500 mb for forecasting the development of Category III lows (when central pressure is more than 1000 mb). In this illustration the up-contour distance is greater than 1200 miles.

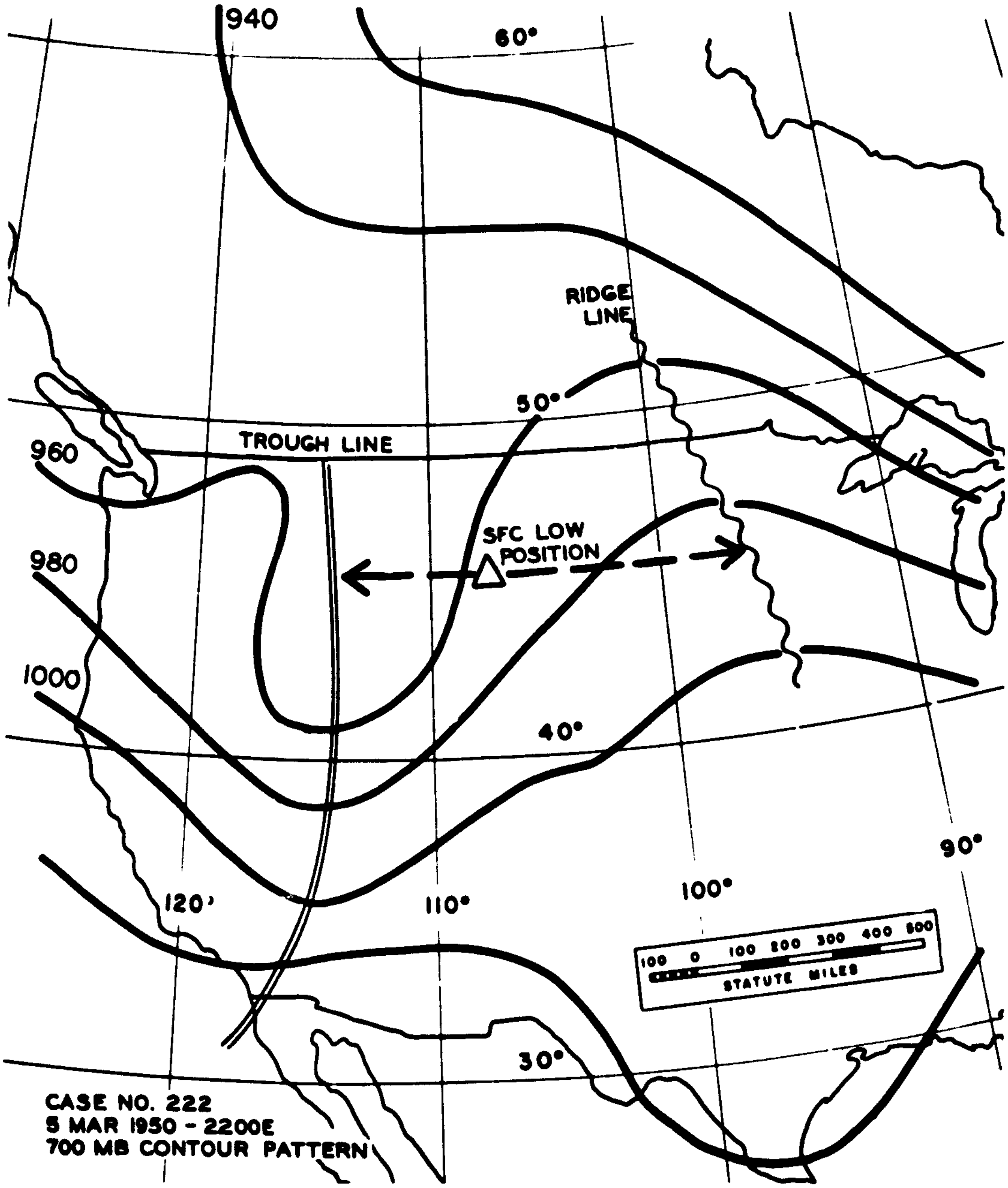


Fig. 56. The measurement of half wavelength at 700 mb for forecasting the development of Category III lows (with a central pressure less than 1000 mb). The wavelength measurement here is 12°.

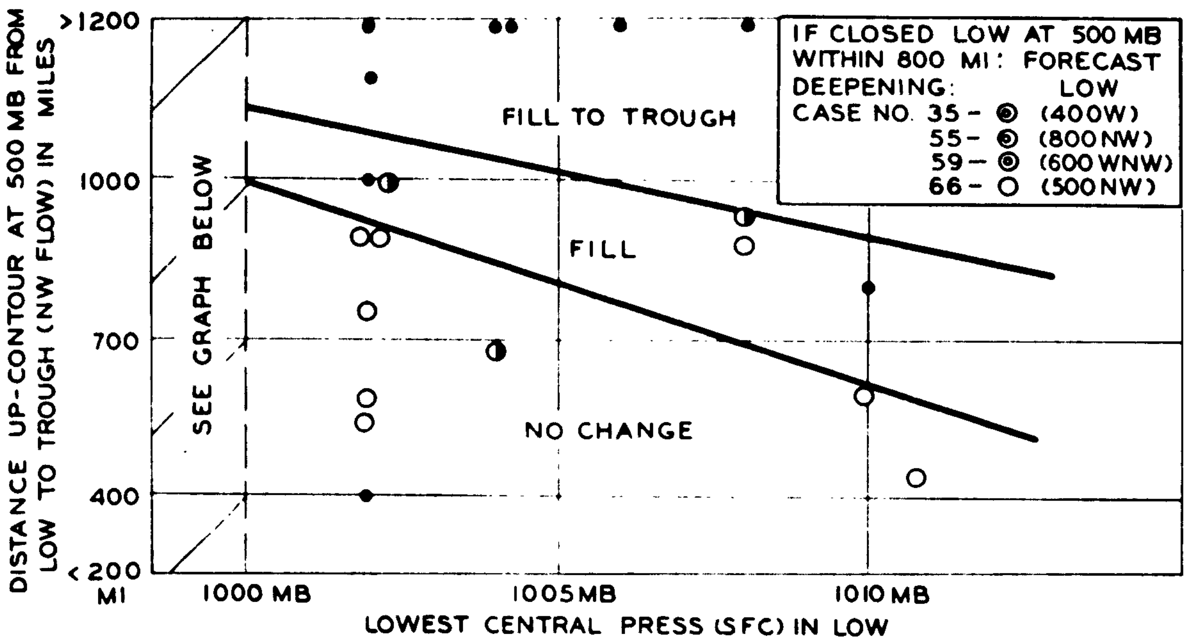


Fig. 57. Development forecast graph for Category III cyclones with central pressure 1000 mb or more.

b. If there is not a closed low at 500 mb, measure in miles the distance up-contour from the low to the edge of the northwest flow (usually, the location of the contour trough). This measurement is illustrated in Fig. 55. Enter Fig. 57 with this distance parameter and the surface central pressure. Forecast intensity changes in accordance with curves on the graph.

3. If the central pressure of the surface cyclone is lower than 1000 mb, then at 700 mb, measure in degrees latitude the half wavelength of the contour pattern along the latitude of the low cell from the trough line to the eastern ridge line. This is illustrated in Fig. 56. At 500 mb, determine the actual contour height directly over the low center. Enter Fig. 58 with these two measurements and forecast the intensity change accordingly.

The forecasting graphs in Figs. 57 and 58 contain the entire data sample, including the independent control data. Tables 1 and 2 of Appendix V present the specific measurements for all cases. The significance of the graphs is apparent without statistical evaluation. A sample work sheet designed for practical application of this technique is presented at the end of this section.

1.5. MOVEMENT

The prognosis of movement of Category III storms is important. As pointed out earlier, errors in this forecast are most common because the track of the cyclone is across the prevailing flow aloft. Unfortunately, the majority of these cyclones, while well-developed and covering a large area, have a flat multi-centered core which makes it difficult to define any one point as the "center." For this reason, the movement forecast presented here will deal with the primary track of the cyclone and not with the detailed prognosis of direction and speed.

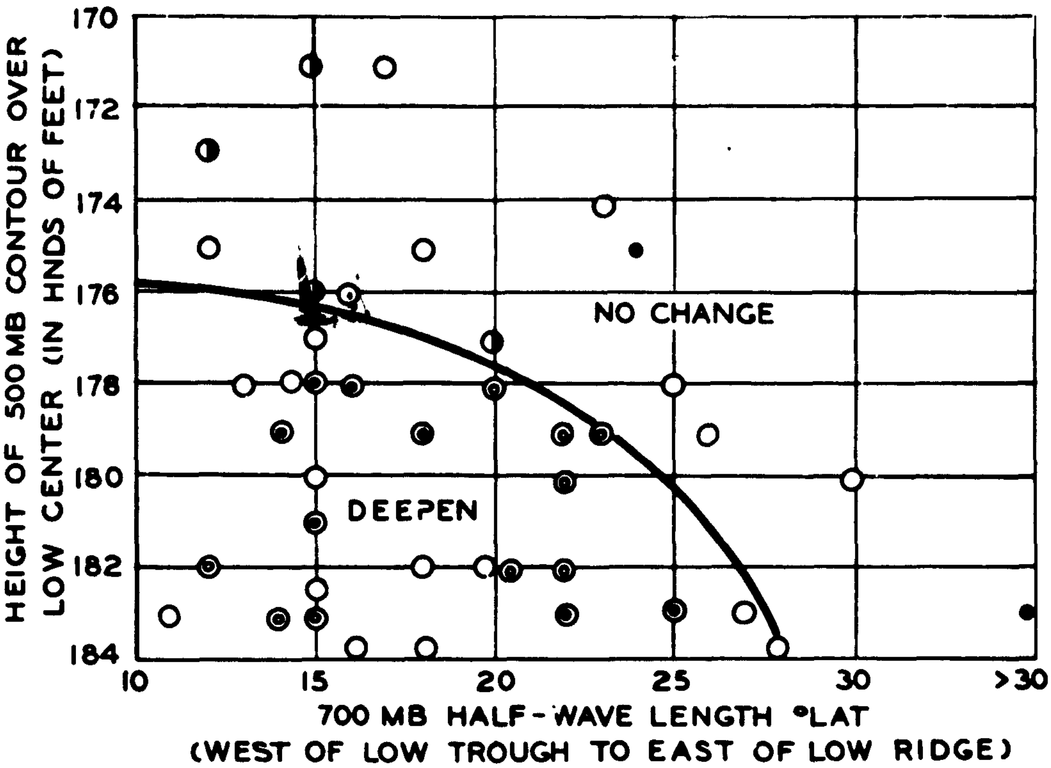


Fig. 58. Development forecast graph for Category III cyclones with central pressure less than 1000 mb.

An identical movement analysis has been performed by George (1949) in connection with a group of cyclones moving southeastward across the upper air flow. Essentially, this analysis established the fact that the future path of the cyclone is to a large degree dependent upon the thermal pattern in the area at 700 mb. The present investigation has shown that the development of the storm is likewise important.

If the cyclone is forecast to fill (based on Figs. 57 and 58), it should be assumed the track will be predominantly south, regardless of thermal patterns aloft. This appears to be accurate when filling to a trough is forecast, with lesser significance when only slight filling is involved. Few cases are involved here, less than 20 percent of the data sample. Figure 59 shows an example and the subsequent path of a Category III cyclone that filled to a trough. It is common for the path to be along the edge of the mountains. It should be borne in mind that this movement is not typical of Category III cyclones which do not fill.

Category III cyclones forecast to deepen or to remain unchanged are more common than those forecast to fill and have a different pattern of movement. These systems move southeastward across the flow pattern to the southern edge of the isotherm ribbon (referred to as the thermal crest area) on the 700-mb chart at the time of classification, thence recurving and "steering" with the 700-mb contour-flow at that point in the pattern. The cyclones frequently maintain fixed positions relative to the contour-thermal patterns which are translating with the wind flow at 700 mb; however, the instantaneous picture, i.e., the location of the thermal crest on the chart for the time of classification, gives highly reliable results in showing the future track of the low. An example of a deepening Category III cyclone following this track is given in Fig. 60.

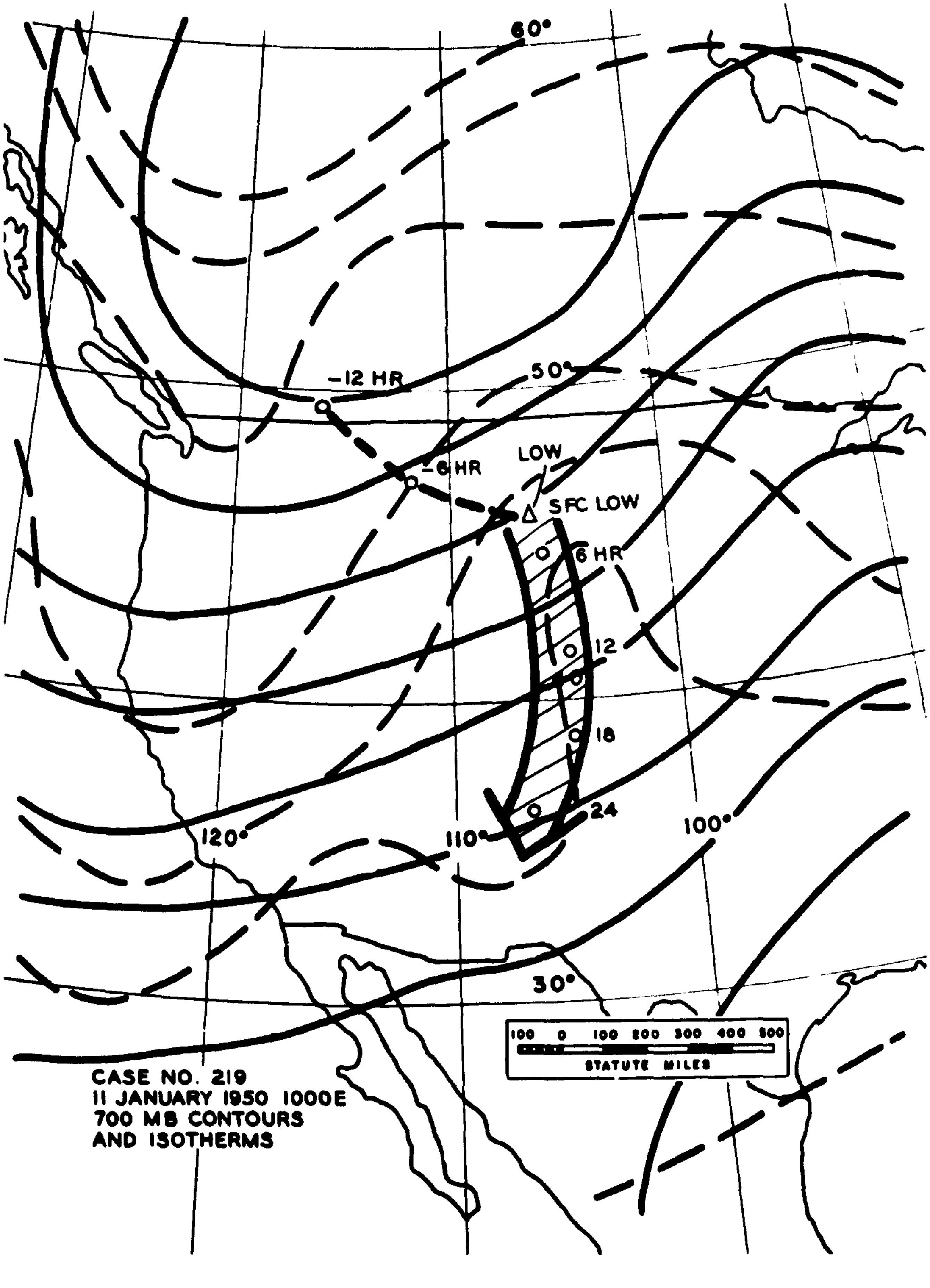


Fig. 59. An example of a Category III cyclone forecast to fill-to-trough and its track due south. The past track is also shown.

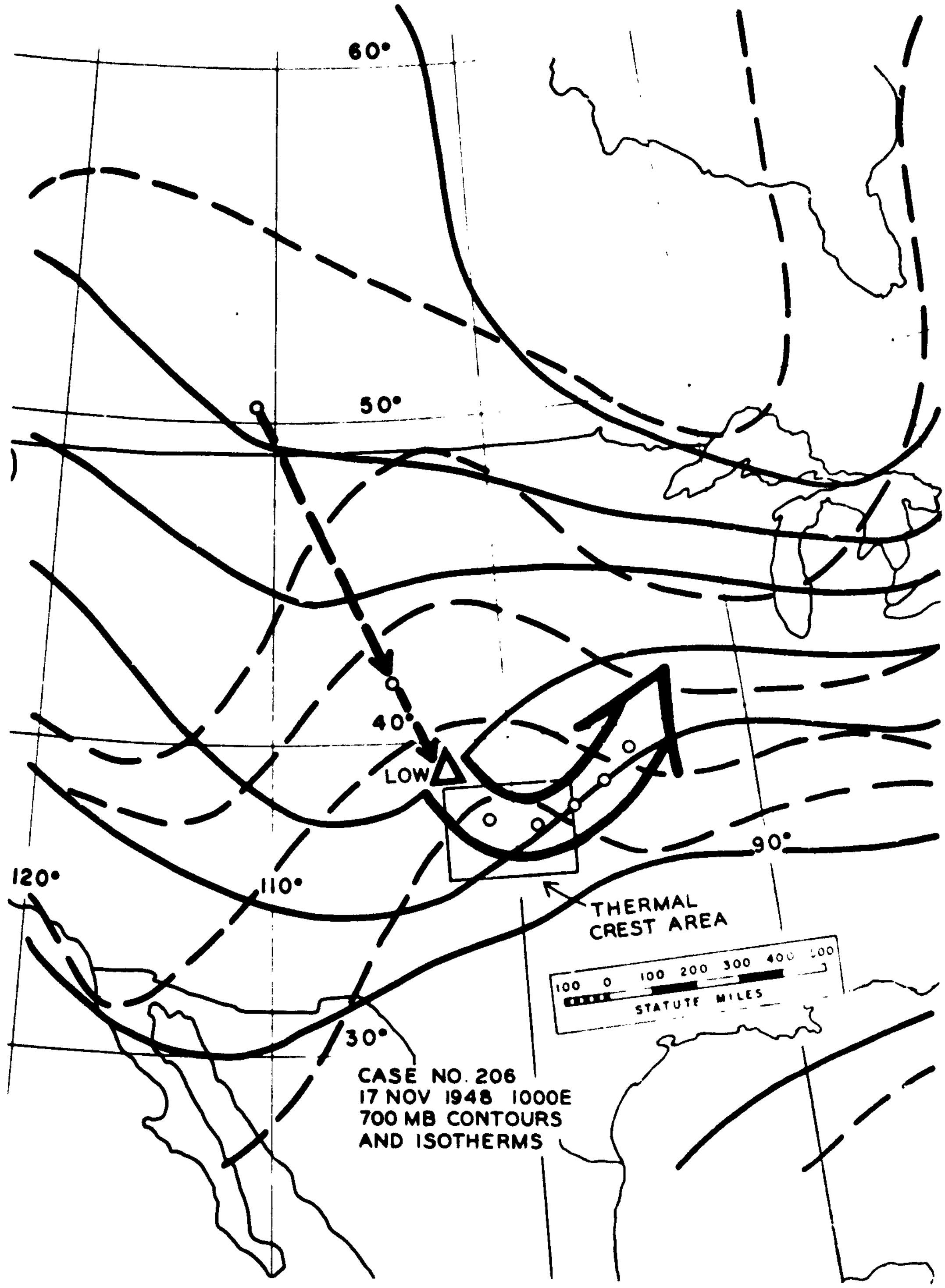


Fig. 60. An example of a Category III cyclone forecast to deepen and its track. Note the pronounced isotherm ribbon and thermal crest. From a "snapshot" viewpoint, the cyclone moves south into the crest area and then recurves, moving with the 700-mb contours over the recurvature point.

In forecasting movement of these cyclones by the above technique, it is necessary to delineate somewhat subjectively the thermal crest and the isotherm ribbon. The general rule is that the southern edge of the ribbon is at the isotherm south of which the spacing is about double that between the widest spaced isotherms in the ribbon. Figure 60 illustrates a well-defined ribbon. It was found in this investigation that the thermal crest center is a fairly accurate point of recurvature; however, a refinement is possible by considering the original location of the cyclone. If located south of 35° latitude, the cyclone will recurve 200–400 miles *north* of the thermal crest area (and in these cases, the ribbon is usually poorly defined); if located north of 45° latitude, the cyclone tends to recurve 200–400 miles south of the thermal crest area. Cyclones located between 35–45° latitude recurve very close to the ideal crest-point.

Earlier, it was noted that Category III cyclones were often multicentered. An investigation of this feature proved interesting although not especially helpful. Cyclones located north of approximately 45° latitude divide into two cells when recurving, the primary cell behaving as described heretofore. The secondary cell usually remains in the lee-of-the-mountain area, and must be treated as an independent cyclone according to its category classification. However, when the Category III cyclone is located south of about 35° latitude, it does not clearly divide as it recurves and for all practical purposes it remains as a single cyclone. In the 35–45° zone, recurving cyclones may or may not leave behind them another low pressure cell.

As mentioned before, the speed of movement of Category III cyclones was not amenable to treatment. However, a general statement may be of value: Category III cyclones will move rapidly (at the extrapolated speed or faster) until they reach the recurvature point; thereafter, rapid deceleration usually occurs as the cyclones head northeast. A sample work sheet is presented on page 92 for forecasting the movement of Category III cyclones.

WORK SHEET FOR FORECASTING CATEGORY III CYCLONES

REQUIREMENTS: Sea level cyclone of reasonable stature, located beneath southwest flow at 700 mb, with a past track from the northwest.

Date.. **Time SFC Map**.. .. .. **Time Upper Air**. .. ..

LOCATION OF CATEGORY III CYCLONE.. .. ..

DEVELOPMENT:

1. From surface synoptic chart, the lowest central pressure of cyclone is .... mb.
2. If central pressure is 1000 mb or higher, mark position of surface low on the 500-mb chart, ignoring 3-hr time lag between surface and upper air maps.
   - (a) If there is a closed low at 500 mb within 800 miles of the location of the surface cyclone, FORECAST DEEPENING OF THE LOW. *Yes* or *No.*
   - (b) If no closed low at 500 mb, measure distance in miles, at 500 mb, up-contour from the low to edge of northwest flow (usually contour trough).

     This distance is .. .. mi.

     (From 1.) Central pressure of low is .. .. .. mb.

   Enter Fig. 57 with these two values and FORECAST FILLING, or NO CHANGE, as indicated.

     Forecast: . .. .
3. If central pressure is less than 1000 mb, mark location of low at both 700- and 500-mb charts (ignoring 3-hr time lag).
   - (a) At 700 mb, measure in degrees latitude the half wavelength, measuring along latitude of low from the trough west to the ridge east.

     HALF WAVELENGTH IS . . . . °.
   - (b) At 500 mb, determine height value of contour over low center in hundreds of feet.

     500-mb HEIGHT IS .
   - (c) Enter Fig. 58 with (a) and (b) values, and FORECAST NO CHANGE, or DEEPENING, as indicated.

     Forecast: . . . .

VERIFICATION:	Initial intensity count	.. ..
	Intensity count 30 hrs later	.... .
	Change in intensity:	.. Class ... .

MOVEMENT: From Development forecast above, low is *filling* or *nonfilling.*

1. If low is *filling* (either fill-to-trough, or filling), forecast movement of cyclone generally south. No speed forecast is provided. Forecast . . . .
2. If cyclone is nonfilling (either no-change, or deepening), locate cyclone on the 700-mb chart. LATITUDE OF LOW IS .... °.

D I R E C T I O N

- (a) Examine 700-mb chart for thermal-crest area. Mark this "recurvature area" on map.
  - (1) If latitude of low is north of 44°, move cyclone along shortest path to point 200–400 miles *south* of recurvature area. Thereafter, recurve low with 700-mb flow over this point.

    LOCATION ....
  - (2) If latitude of low is 35–44°, move low along shortest path to recurvature area; thence recurve with 700-mb flow. ....
  - (3) If latitude of low is south of 35°, move cyclone along shortest path to point 200–400 miles *north* of recurvature area (usually poorly defined in these cases). Thence, recurve low with 700-mb flow.

    .. ..

S P E E D

- (b) In general, these cyclones move faster than extrapolated speed to the recurvature area, or point.

  FORECAST SPEED ....

  After recurvature, deceleration will occur as low becomes "steered."

  FORECAST SPEED ....

3. Cyclones north of 44° usually leave a well-formed secondary cell west of them as they recurve. Forecast this secondary low as an independent cyclone. Cyclones south of 35° usually do not leave a secondary cell, but recurve as a single well- shaped cyclone.

VERIFICATION:	RECURVATURE AREA:	FORECAST	. . ..	ACTUAL	. .... .
	SPEED before recurvature	FORECAST	.. ... .	ACTUAL	.. .. .
	SPEED after recurvature	FORECAST	.	ACTUAL	. . . . .

CATEGORY IV CYCLONES

R. J. SHAFER AND P. W. FUNKE

1.1. INTRODUCTION

By definition, Category IV cyclones are located under southwest flow and are moving from the southwest. These cyclones are common over the eastern half of the United States and are generally regarded as deepening type storms; they occur as frequently as ten times per month. For the purposes of this study, the following definitions and requisites apply:

a. The surface cyclone is located under flow from the southwest quadrant at 850 mb, 700 mb, and 500 mb. Flow from north of west over the surface low precludes treatment under this section.

b. The history of movement of the cyclone must also be from the southwest quadrant for at least 12 hours prior to the time at which the forecast is made.

c. No attempt should be made to apply these techniques to "secondary" type storms until such "secondaries" have become established entities (i.e., a valid, separate and closed surface circulation has existed for at least 12 hours).

d. While not a requisite, it should be noted that no storms have been included in the independent or dependent data whose position at the time of forecast was west of the 95th meridian. It was believed desirable to rule out as far as practical all possible orographic effects.

In contrast to Category I cyclones, which display a general tendency to fill, Category IV cyclones generally tend to deepen.

1.2. APPLICATION

All forecasts are for a 30-hour period which begins with the time of the synoptic surface data. In the section dealing with speed and direction of movement, the forecast values will be the 30-hour average speed and direction. With some cyclones, frequent accelerations and course shifts make application of these values for periods shorter than 18 to 24 hours questionable.

1.3. MEASUREMENTS

In studying cyclones of this category, considerable use has been made of the areas of cross-isotherm flow at 850 mb. These areas have also been called areas of "apparent warm or cold advection." It is recognized that these are not necessarily areas of real advection. The area of "apparent warm advection" at 850 mb is normally located in the northeast quadrant of the surface low in question, and the area of "apparent cold advection" in the southwest quadrant.

For simplicity of measurement, these large areas of cross-isotherm flow have been further defined to have centers of action, designated A_w and A_c, for the warm and cold cross-isotherm flow respectively. As shown in Fig. 61, these centers can be located objectively. The position of the surface cyclone is marked on the 850-mb chart. Contour lines south of this low position that are part of the 850-mb trough system are noted. The forecaster may use his discretion in selecting one contour north of the low position if it is clearly part of a broad belt and channels the low with the next higher numbered contour. In the case of a closed contour system at 850 mb, the innermost height line should not be used. If the system is flat, it is

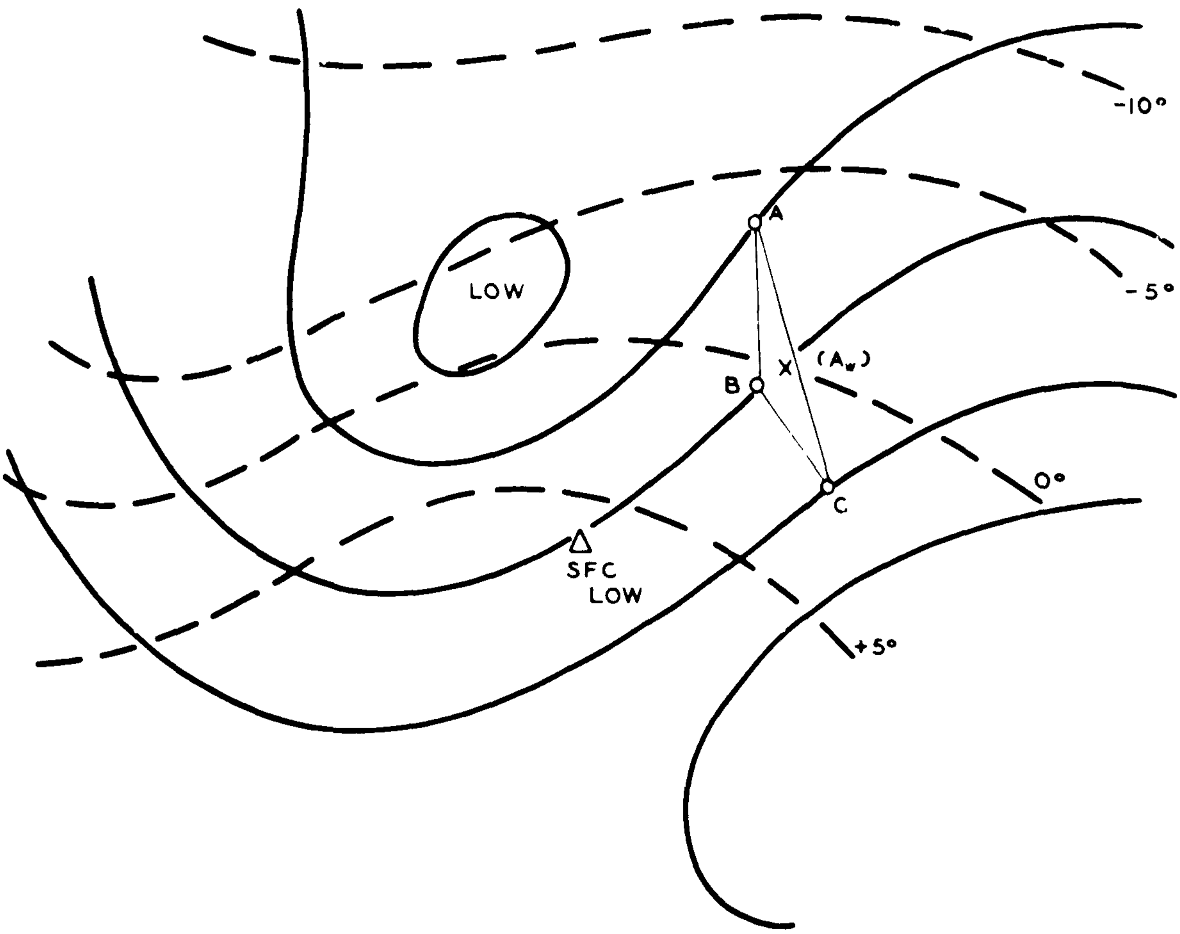


Fig. 61. Location of A_w, 850 mb. Warm cross-isotherm flow on the inside open contour ranges from about +4 to −11 or an average temperature of about −3½. This locates point A. Similarly, points B and C are found. The "center of gravity" (or A_w) of the triangle is then located at X. Note that the contour on the southeast is not a valid one, since it does not extend through the trough line. The inside closed contour is never a valid height line.

advantageous to draw supplementary 100-foot contours for greater detail. (Note that if one such line is drawn, all must be drawn.)

Usually 3 or 4 contours will meet the above requirements. On each of these contours, trace back to the point where the warmest air is observed and note this temperature. Then proceed downstream along the contour until the indicated warm advection ceases and record this temperature also. Compute the average of these two temperatures and mark the point corresponding to this average temperature on the contour. After the operation has been carried out for each of the valid contours, connect the points by lines to form a polygon and by visual observation locate the "center of gravity" of the polygon. Proper weight should be given to a cluster of points if one exists. The center of gravity of the polygon is defined as A_w. Frequently the average temperatures will fall on a straight line and A_w will be the "balance" point of the line. A_c is found in a similar manner except that the contour is followed upstream from the warm temperature until cold cross-isotherm flow ceases. All measurements in this section are made in statute miles and in centigrade degrees. Troughs are located as nearly as possible by use of the wind data.

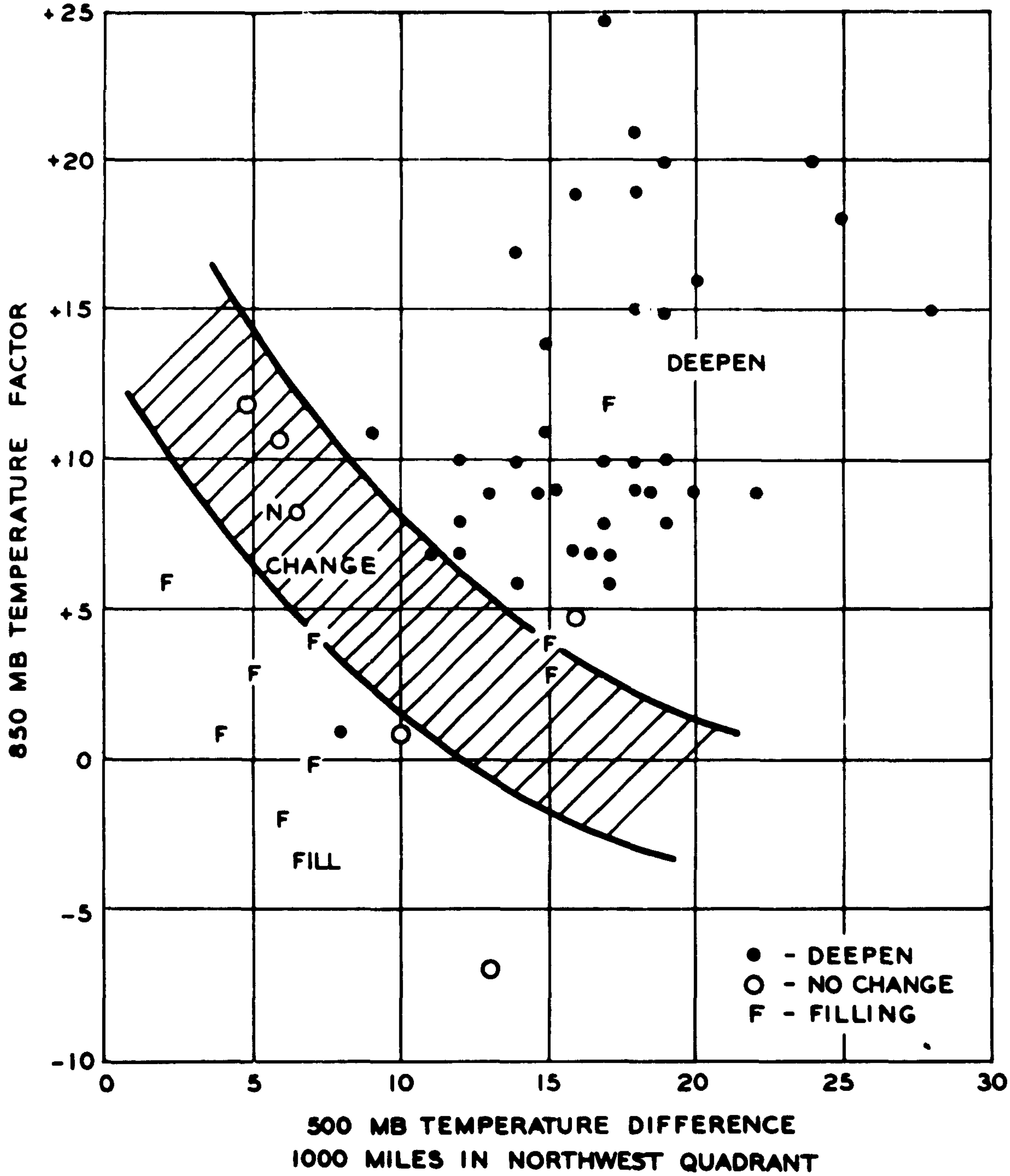


Fig. 62. Deepening or filling. A categorical forecast can be obtained for any cyclone whose initial intensity count is *less than 15*. The ordinate, the 850-mb temperature factor, is illustrated in Fig. 77, and the abscissa in Fig. 64. When the 500-mb trough line is greater than 800 miles from the surface position of the low, measured along the latitude of the low, forecast a filling tendency in the 30-hour period.

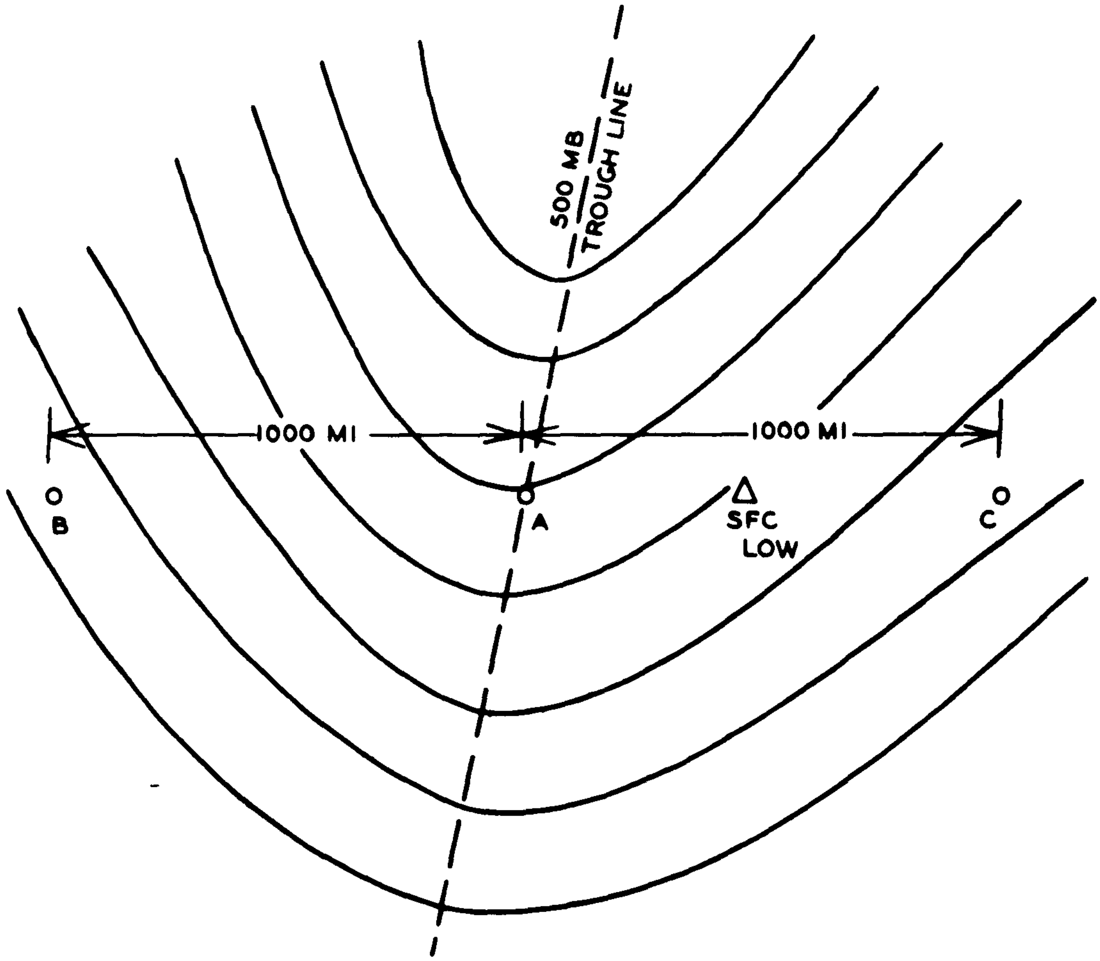


Fig. 63. Trough sharpness, 500 mb. Measure 1000 miles east and west of the 500-mb trough line at the latitude of the surface low. Find the maximum height difference *BA* and *AC* and add. Assuming 200-ft contours, in this case the difference *BA* is about 700 ft and *AC* is about 500 ft for a total of 1200 ft. This value is then corrected for latitude by use of the table on page 20 and becomes the trough sharpness.

1.4. DEVELOPMENT OF CATEGORY IV CYCLONES

Early in the study of these cyclones, it appeared that deepening and filling should be investigated in relation to speed and steering. Although no direct results of this kind were obtained, a relationship was discovered which enables an accurate development forecast to be made for certain of the low intensity cyclones of this category.

Figure 62 illustrates this relationship. It can be used to give a quick answer to whether deepening, no change, or filling will occur during the 30-hour period. One of the parameters used in the figure is called the 850-mb Temperature Factor. It depends, to some degree, on the phase relationship between the wind field and the temperature field and also to some extent on the strength of the thermal structure at 850 mb. This parameter is discussed more fully in the section concerned with direction of movement (p. 116) and is

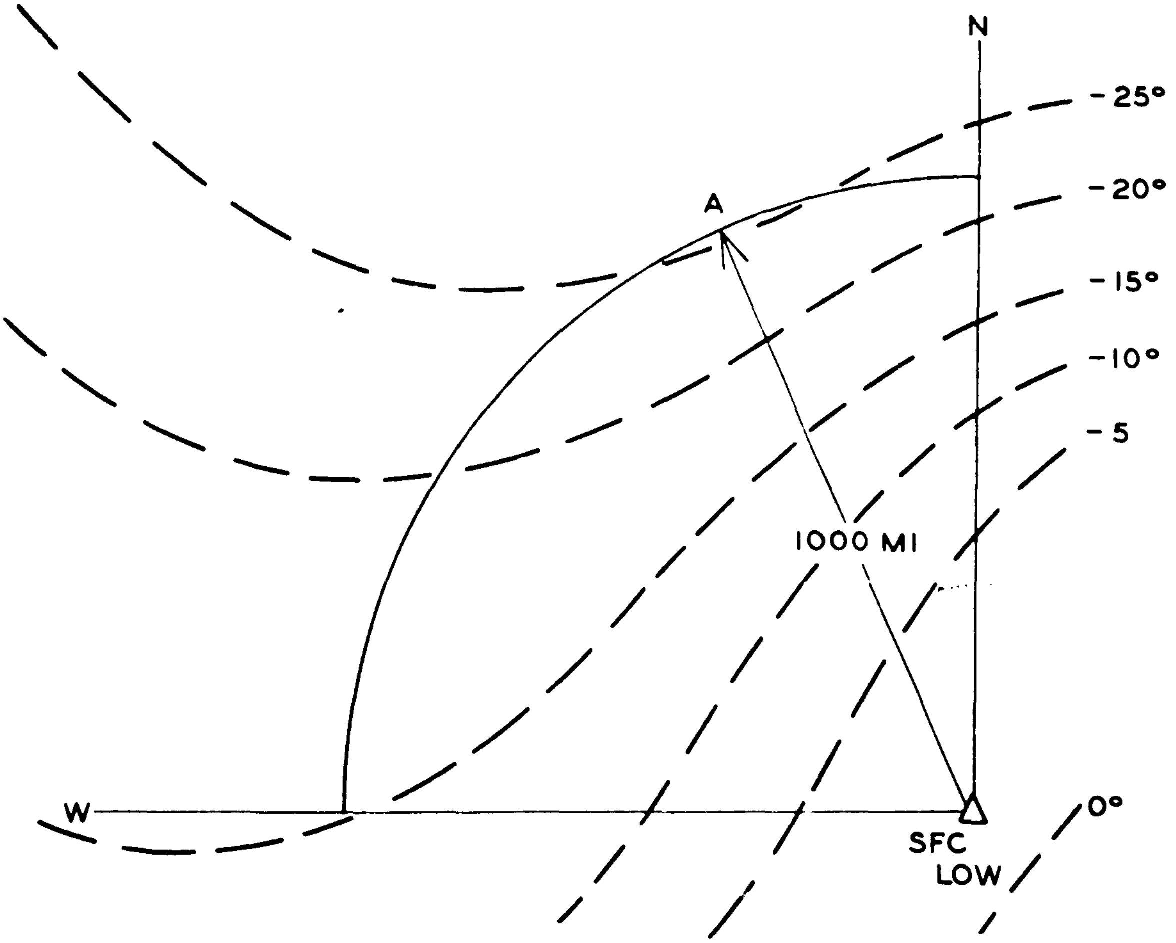


Fig. 64. Strength of the temperature field, 500 mb. Find the maximum temperature difference between the position of the surface low and an arc 1000 miles in the northwest quadrant at 500 mb. In this case it is about 24°. This technique is also used at 850 mb and 700 mb for the determination of speed of movement parameters.

shown also in Fig. 77. The second parameter, along the abscissa, is the maximum temperature gradient within 1000 miles measured at 500 mb in the northwest quadrant from the position of the center of the surface low. This measurement is shown in Fig. 64. It has been found that the relationship between these two parameters is valid only for cyclones of small initial intensity (i.e., cyclones whose initial intensity count is less than 15).* For these low intensity cyclones, it appears from Fig. 62 that a prime requisite for deepening is the presence at 500 mb of a broad, steep gradient of temperature to the northwest of the surface low with a marked tongue of cold air to the west of the 850-mb trough line.

It would be expected that the circulation around deepening cyclones would be such that warm and cold air would be brought into the circulation around the low. This implies that advection, proportional in intensity to wind speed and temperature gradient, would be indicated on the charts. Excellent results were obtained using a variation of this technique at 850 mb on large intensity cyclones (intensity greater

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* See page 18 of the Introduction of this report for a discussion of intensity counts.

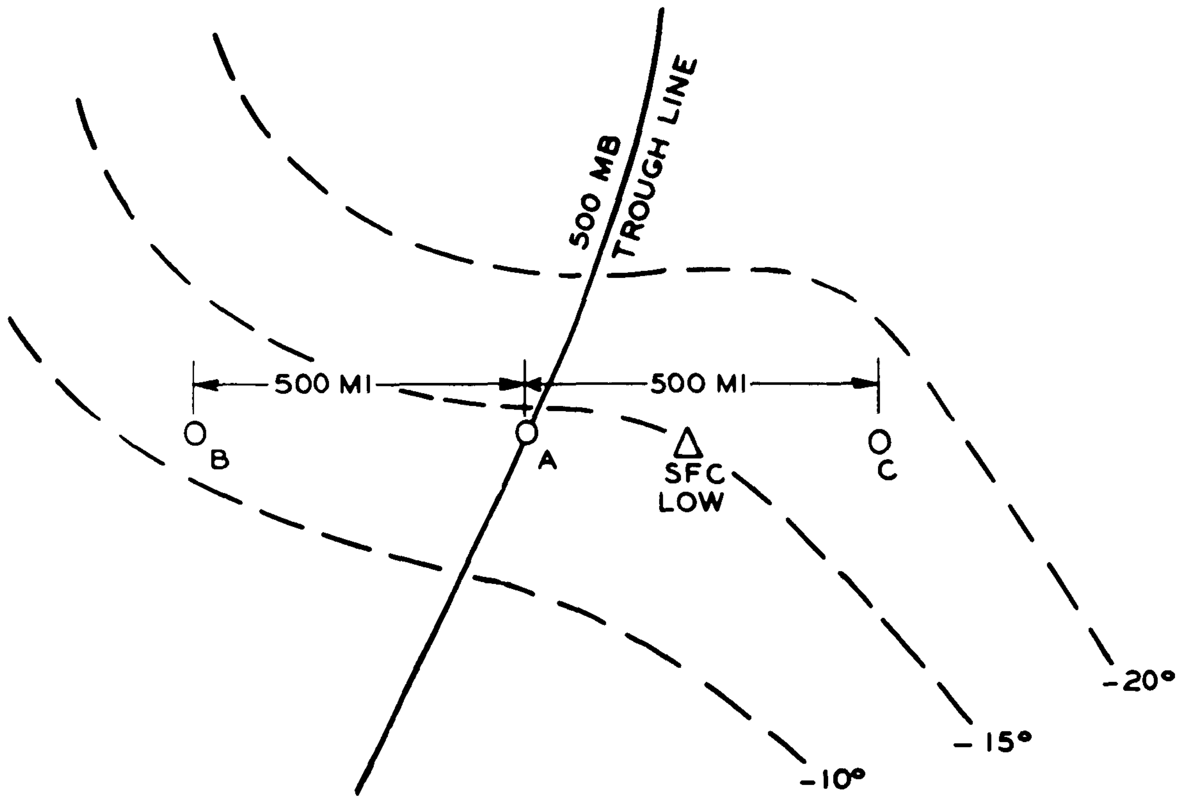

Fig. 65. The 500-mb temperature factor. Measure 500 miles east and west from the 500-mb trough line (*A*) at the latitude of the surface low. Find the magnitude of the temperature difference between point *B* and point *C*. The 500-mb temperature factor is this difference prefixed by a positive (+) sign if the colder temperature is at *B* and a negative (−) sign if *C* is colder. In this case the temperature factor is about −7°.

than 16). However, the advection parameter (to be explained later), when tested on cyclones of lesser intensity, showed increasingly poorer results as the initial intensity decreased.

Although application of the 850-mb advective technique to small storms seems valid, small intensity lows that have ill-defined temperature and flow characteristics sometimes increase their circulation 5 or 6 times within 30 hours. More mature storms have stronger temperature and wind fields, therefore the following rules may be stated:

1. The 850-mb advective measurement is more effective when applied to cyclones of large initial intensity than to smaller lows. It seems reasonable also that the energy requirements necessary to double the circulation of a cyclone of intensity 5 will not be the same as those needed to double a size 20 storm. It is possible also that there is an inertial parameter which is proportional in some degree to the intensity of circulation.

2. The initial intensity of the cyclone is a *parameter in itself*.

3. Cyclones of small initial intensity will not become major, intense storms unless the character of the 500-mb trough and associated temperature field is sharp, well marked and relatively strong in gradient (or potentially so). If the 500-mb trough does not exhibit these characteristics, the weak

cyclone will not deepen into an intense storm despite favorable conditions at 850 mb. This result is in agreement with Austin (1951) who found that the development of cyclones is mainly a function of high level parameters.

As a possible corollary to the rule above, the following was noticed: all cyclones with large initial intensity counts meet the criteria of rule 3; therefore these criteria cannot be used in forecasting their development. The location and intensity of low level advection are the best indications of their future development.

The objective forecasting technique for development of Category IV cyclones is based on these three points:

1. The initial intensity of the circulation is a parameter common to all storms.
2. The low level (850-mb) advection measurements give the best parameters for predicting development of high initial intensity storms.
3. The high level (500-mb) parameters are the best indicators of the future development of cyclones with low intensity at the beginning of the forecast period.

1.5. OBJECTIVE FORECASTING TECHNIQUE FOR PREDICTING DEVELOPMENT

Considerable effort was expended in developing objective measures for the definition of the 500-mb trough (mentioned in rule 3). Through the use of composite charts and subjective methods, the following elements have evolved:

a. The "sharpness" of the trough.
b. The strength of the temperature field.
c. A phase relationship of the wind trough and the thermal trough.

The "trough sharpness" is proportional to the cyclonic circulation across the trough line at the latitude of the surface low. It is measured mechanically by marking the trough line at the latitude of the surface low and measuring 1000 miles east and west of the trough line at the same latitude (see Fig. 63). The height difference in feet between the extreme western point and the trough line is added to the height difference found similarly 1000 miles east. This sum is then corrected for latitude using the table in Appendix VI and is defined as the "trough sharpness." In essence, we have a figure proportional to the north component of flow west of the trough and the south component east of the trough, and when added together, the resulting figure becomes proportional to the strength of the cyclonic circulation at the 500-mb trough at the latitude of the low.

The strength of the temperature field is the parameter previously used in Fig. 62. It is determined by swinging an arc on the 500-mb chart from the position of the surface low center 1000 miles in the northwest quadrant of the low (Fig. 64). The maximum temperature difference between the position of the low and the 1000-mile arc defines the strength of the temperature field.

The third parameter for the 500-mb surface is analogous to the 850-mb temperature factor and is called the 500-mb temperature factor. It is found by again marking the 500-mb trough at the latitude of the surface cyclone and measuring points 500 miles east and west of the trough at the same latitude (see Fig. 65). The temperature difference between the extreme western and eastern points is the magnitude of the temperature factor. The sign is determined by noting which of the temperatures is the colder. A plus sign is prefixed if the colder temperature is west and a negative sign if the warmer air is west. This measurement

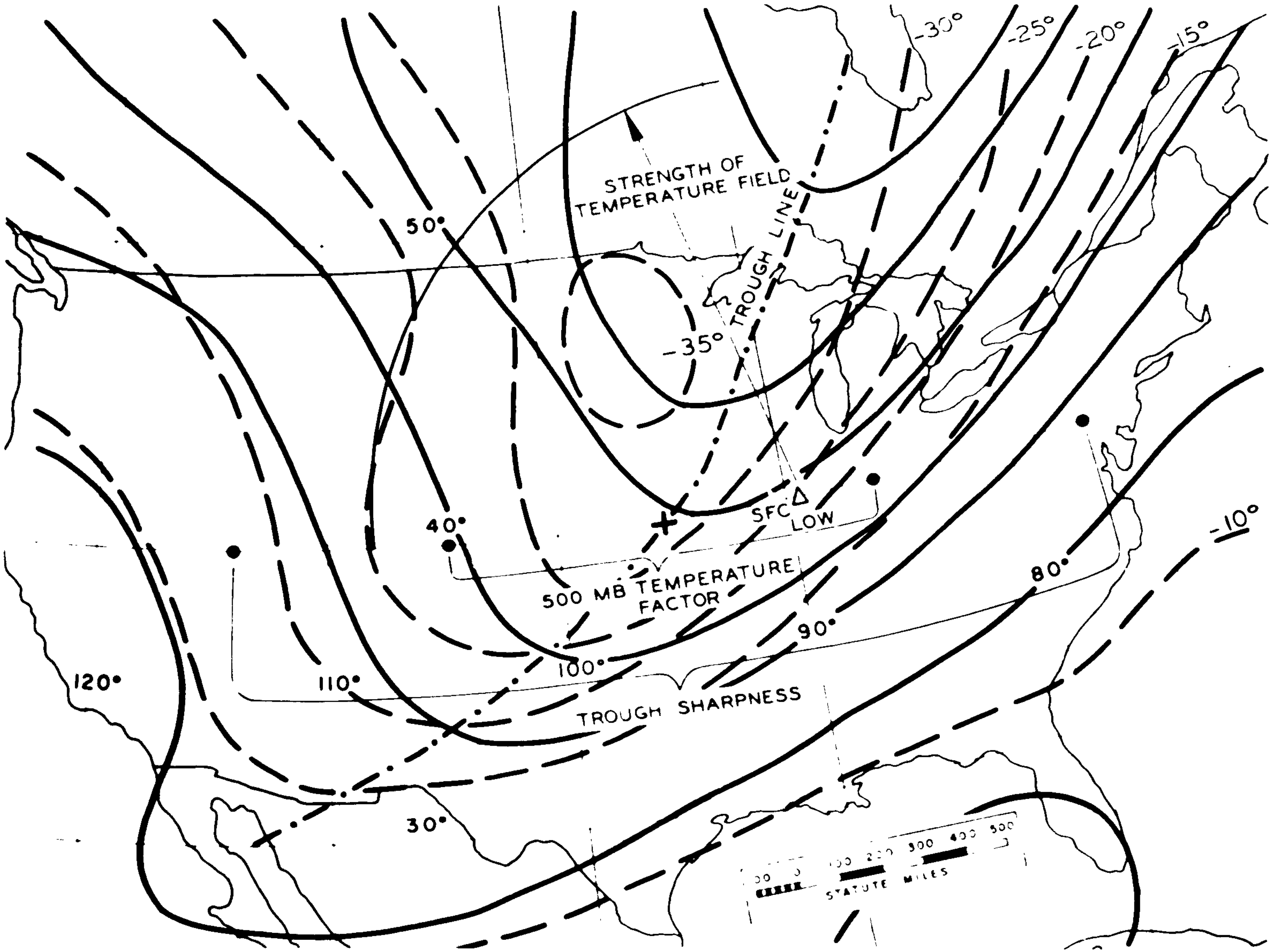

Fig. 66. Composite of 500 mb measurements. The trough sharpness is measured 1000 miles east and west of the trough. In this example, assuming 200 ft contours, the sharpness before correcting for latitude is about 450 ft west and about 400 ft east for a total of 850 ft. The 500 mb temperature factor is measured 500 miles east and west of the trough line and in this case is about +9. The strength of the temperature field is the maximum temperature difference between the surface cyclone and a 1000 mile arc in the northwest quadrant. In this case the maximum falls inside the 1000 mile arc and is about 13°.

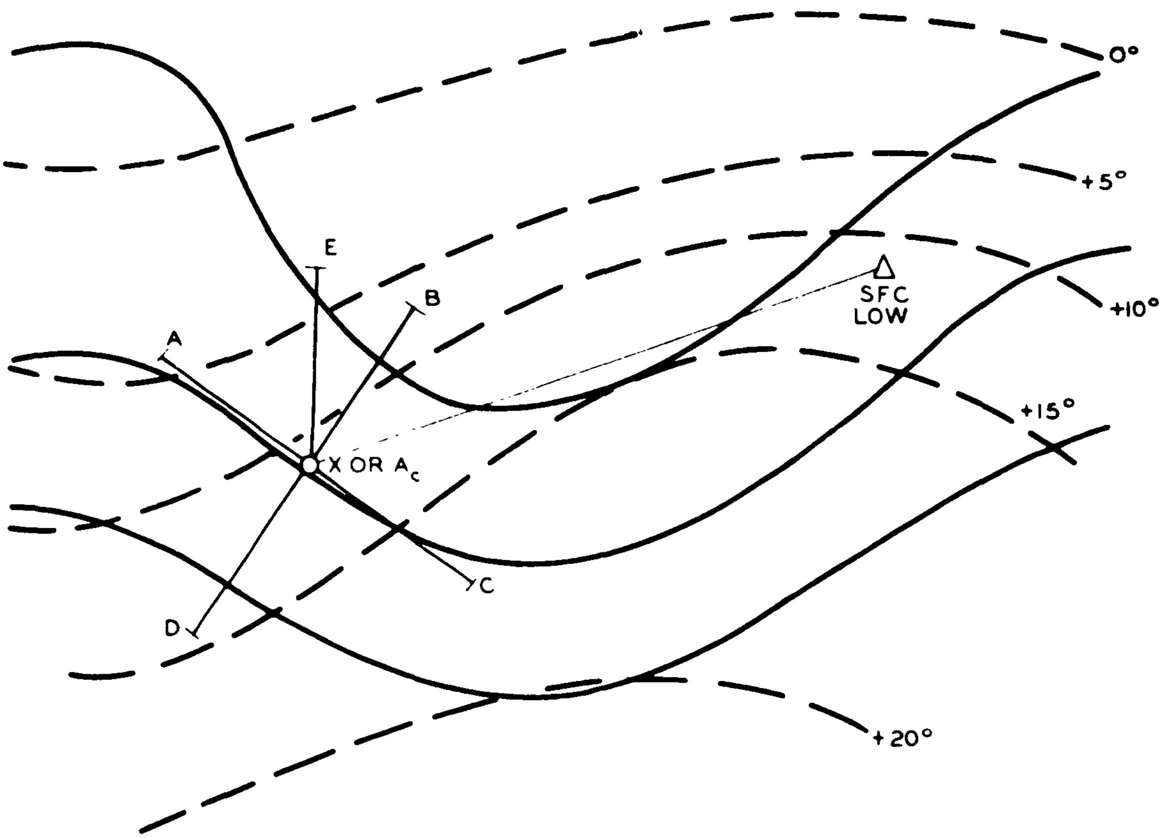

Fig. 67. The 850-mb advective factor. A_c is denoted by X. The line DB is constructed 300 miles on either side of X such that DB is normal to the flow at X. The height difference DB (in feet) is found and corrected for latitude of A_c by use of Appendix VI. The line AC is also 600 miles in length and is constructed perpendicular to DB. The magnitude of the temperature difference from point A to C is recorded. The product of the height difference DB (corrected) and the temperature difference A to C is divided by the total distance of the surface low to X plus the distance XE. (Note: the distance XE is the meridional distance in miles between the latitude of X and the latitude of the surface low.) The quotient is defined as the 850-mb advective factor. In the above example DB is about 500 ft and AC is about 12°.

depends partly on the phase relationships of the cold tongue (if present) and the trough, and it further indicates to some extent the strength of the cold tongue. These parameters seem to give adequate definition of the 500-mb trough with respect to flow and thermal character. A composite view of the 500-mb measurements is shown in Fig. 66.

The parameter chosen to represent the strength of cold air advection at 850 mb needs considerable explanation. In an effort to reduce confusion caused by large numbers of working graphs the process has been reduced to several measurements and several mathematical manipulations. While it may seem involved, in actual practice the *arithmetical* operations will not be overly cumbersome for a forecaster working against time.

The first step is the location of the area of "apparent cold advection" and of the center of gravity of this area, A_c, as described on page 93. Once this center has been found, a straight line 600 miles in length extending 300 miles on both sides of A_c is constructed so that it lies normal to the contour flow at A_c. Determine

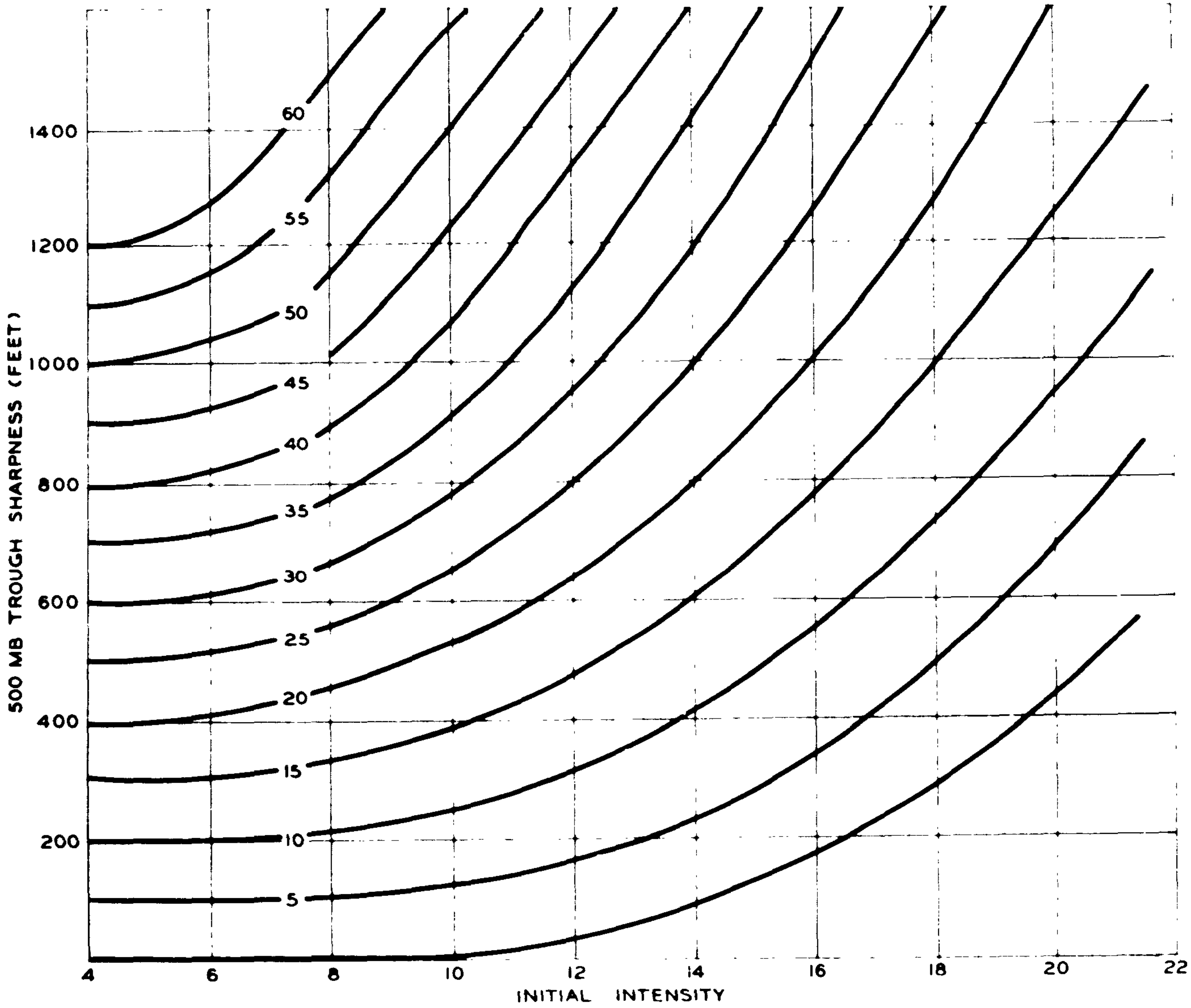

Fig. 68. Intensity forecast, stage 1. Enter the initial intensity (cyclone intensity count at forecast time) on the abscissa and the 500-mb trough sharpness value (Fig. 63) along the ordinate. Record the value determined by this plot with respect to the weight lines.

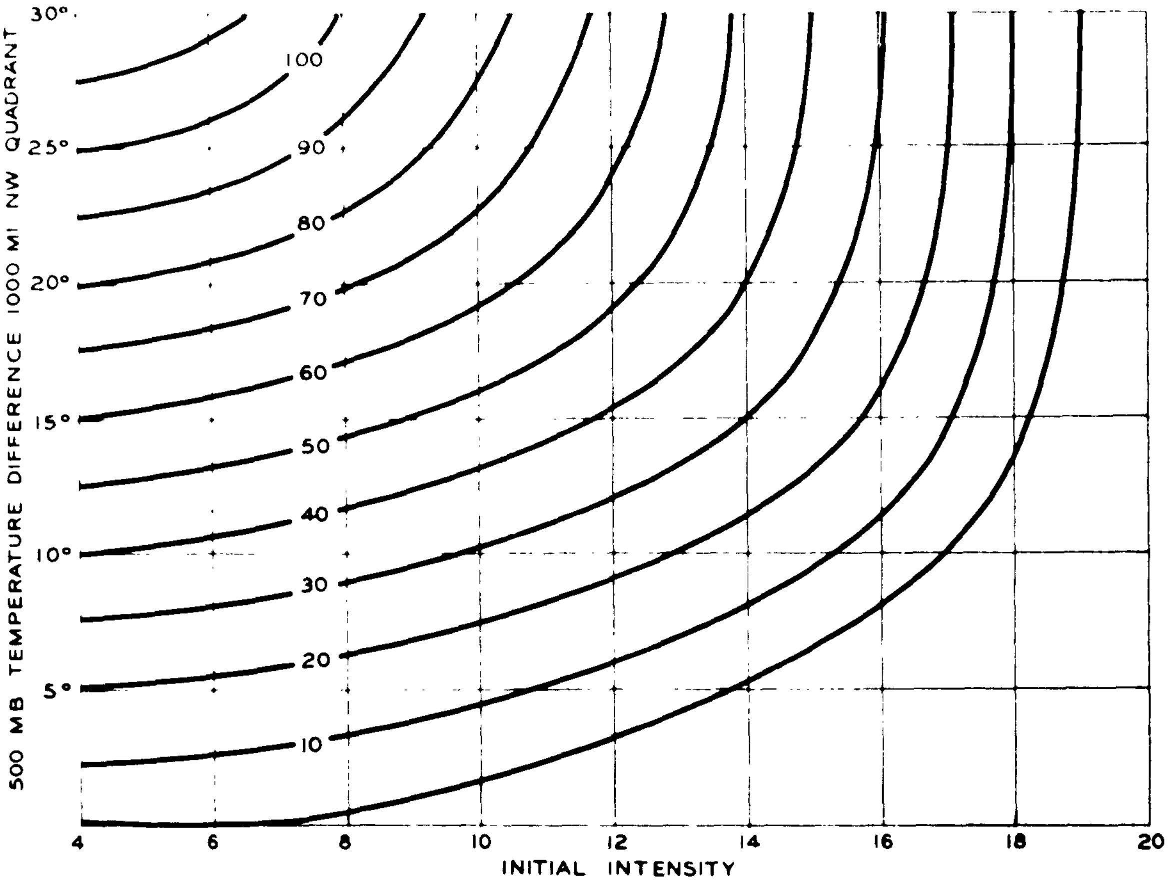

Fig. 69. Intensity forecast, stage 2. Enter the initial intensity on the abscissa and the value representing the strength of the temperature field (Fig. 64) along the ordinate. Record the value determined by this plot with respect to the weight lines.

the height difference in feet between the extremities of the 600-mile line. This difference is then corrected for the latitude of A_c, by means of the table in Appendix VI. The resulting figure is proportional to the strength of flow or wind speed at A_c (Fig. 67).

Now a second straight line, also 600 miles in length, is constructed perpendicular to the first line and extending 300 miles on either side of A_c. (This is then in the general upstream and downstream directions, depending upon how much cyclonic curvature the system has.) The temperature difference between the extremities of this line is determined.

Two values have now been obtained for A_c, a value proportional to the wind flow and one proportional to the temperature gradient normal to the flow vector. The former usually averages 300 to 500 feet and the latter 5 to 25 degrees Centigrade. As the first operation, these two values are multiplied and the forecaster may view the result as representing the strength of the cross-isotherm flow or apparent cold advection at the point A_c.

Active synoptic meteorologists have no doubt recognized at one time or another that cross-isotherm flow (cold or warm) has considerable bearing on the development of cyclonic systems. It seems reasonable to call on synoptic experience in developing this idea further. Therefore, it is assumed that for deepening to occur, there is an optimum distance from the cyclone for cold advection. As this distance (from the low to A_c) increases, its affect upon the deepening of the system probably decreases.

A second factor with respect to the position of the low and A_c is their relative location on the map grid. Again calling on experience, it is normally recognized that the most active deepening occurs when the cold cross-isotherm flow is taking place to the west or southwest. Further, as this apparent advection moves to a position more to the south of the cyclone the storm usually attains maximum intensity and the deepening decreases. Recording the position of A_c relative to the low could be done with a linear measurement and an angle; however, this would cause needless complications in the computations. Instead, the meridional distance in statute miles between the latitude of A_c and the latitude of the surface low is substituted. When A_c is at a latitude north of the low, the distance is taken as zero.

We now have two distances which effect deepening inversely as they increase. They are added together and the sum is usually 700 to 1200 miles. The final step in computing a parameter for measuring the cold air advection at 850 mb is to divide the figure representing the strength of the cross-isotherm flow by the total distance. The final value is called the 850-mb advective factor.

We now have values representing five parameters: the initial intensity of the cyclone, three 500-mb parameters, and one 850-mb parameter. The multiple correlation is accomplished by use of five graphs (Figs. 68, 69, 70, 71, and 72). The abscissa, common to all the graphs, is the initial intensity count of the cyclone. The values of the parameters have been weighted empirically, keeping in mind the three points presented in the preceding section on development. On the three graphs which have the 500-mb parameters as ordinates, the weight lines diverge upwards to the right. That is, more weight is given to a storm with a low initial intensity than to a storm with a high intensity. Conversely on the fourth graph having the 850-mb advective factor as an ordinate, the weight lines slope up to the left thereby giving maximum weight to lows of large initial intensity.

The forecasting procedure is to enter consecutively the parameters in the graphs using the common abscissa, and to record the values determined. These four resulting values are then added and the final graph is entered with their sum and the proper initial intensity. This final graph gives the maximum intensity which the cyclone will attain in the following 30-hour period. Maximum intensity may be reached before the end of the period; therefore filling during the latter part is not precluded. As a further aid to the forecaster, a dashed line extends across the final graph and differentiates deepening and filling storms.* All storms whose final entry falls above the dashed line will be forecast to deepen and those below will be forecast to fill.

The maximum initial intensity of a cyclone is about 21 and the graphs have been cut off at this point. When a cyclone's intensity at forecast time is greater than 21, the forecaster should assume that very little further deepening will ensue and forecast a filling tendency for the end of the 30-hour period. The correlation coefficient between forecast and observed intensities was reduced considerably by two storms which reached the extreme intensity of 37 while only forecast to reach counts of 22 to 27. However, the value of predicting 37 over 27 is questionable since a major storm will occur in either case.

* Filling storms are those that have an initial count greater than their intensity at the end of 30 hours. Thus a cyclone which had initially an intensity of 20 and at the end of the 30-hour period had dropped to intensity 17 would be classed as a filler.

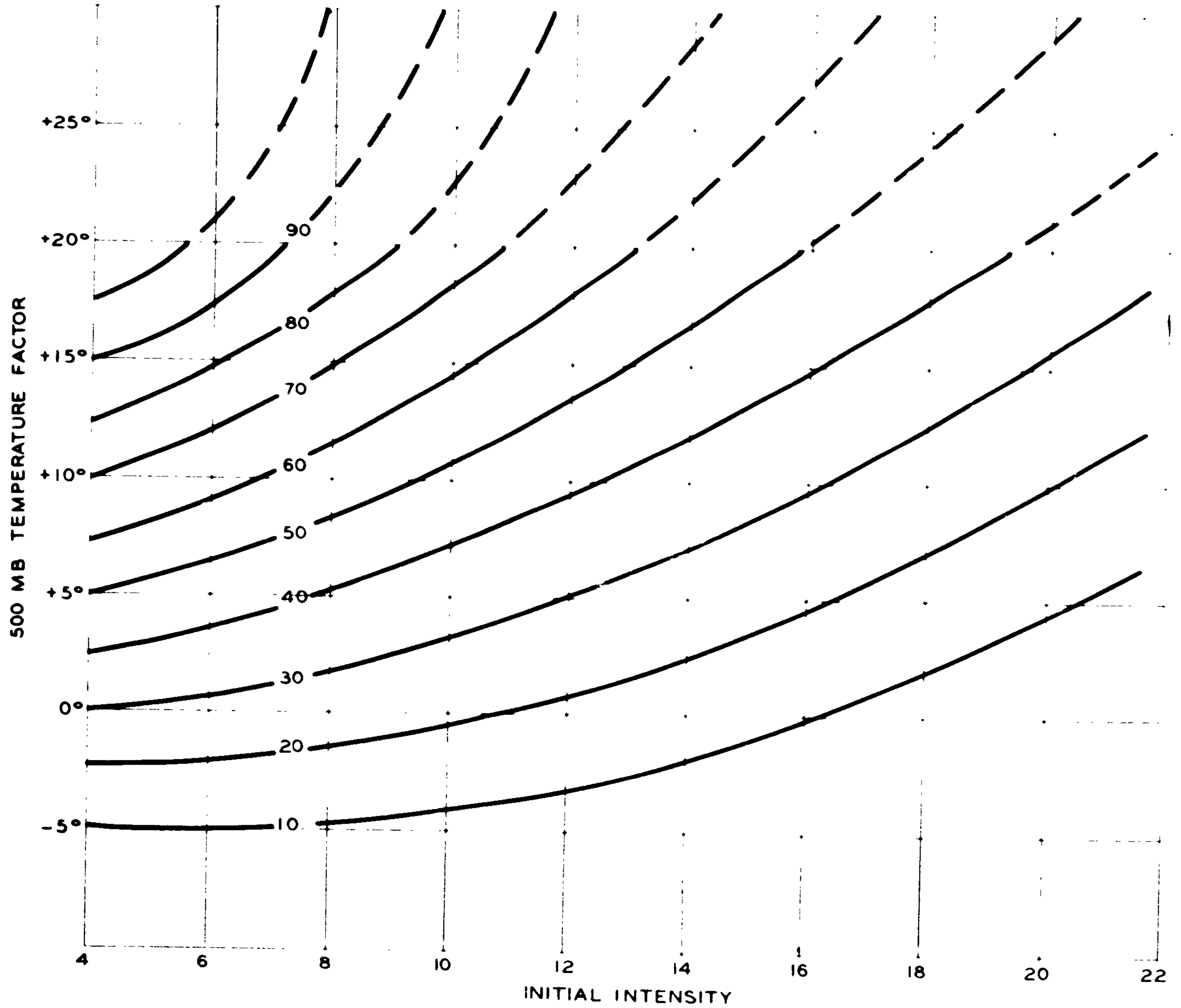

Fig. 70. Intensity forecast, stage 3. Enter the initial intensity on the abscissa and the value of the 500-mb temperature factor (Fig. 65) along the ordinate. Record the value determined by this plot with respect to the weight lines.

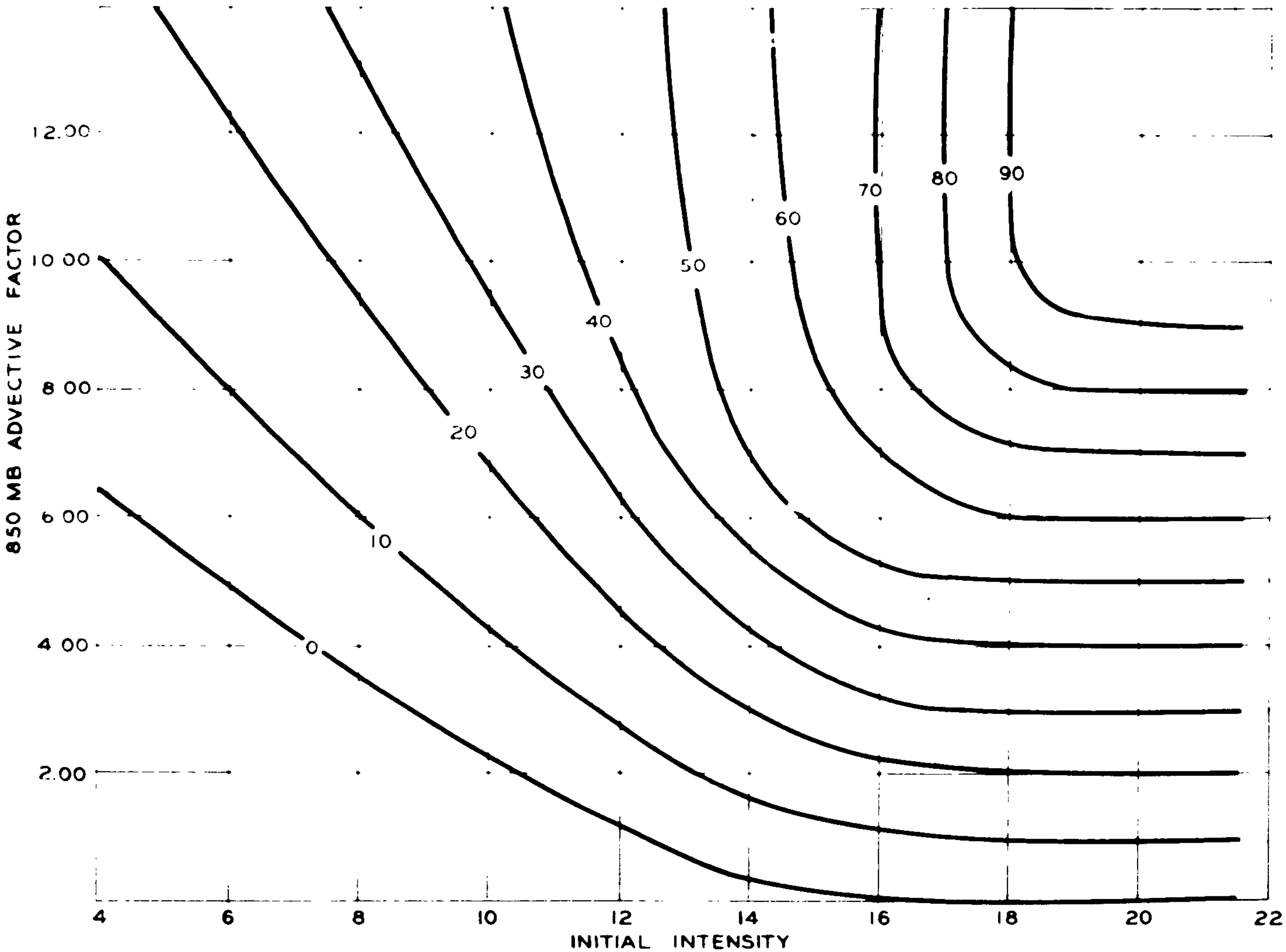

Fig. 71. Intensity forecast, stage 4. Enter the initial intensity on the abscissa and the value representing the 850-mb advective factor (Fig. 67) along the ordinate. Record the value determined by this plot with respect to the weight lines.

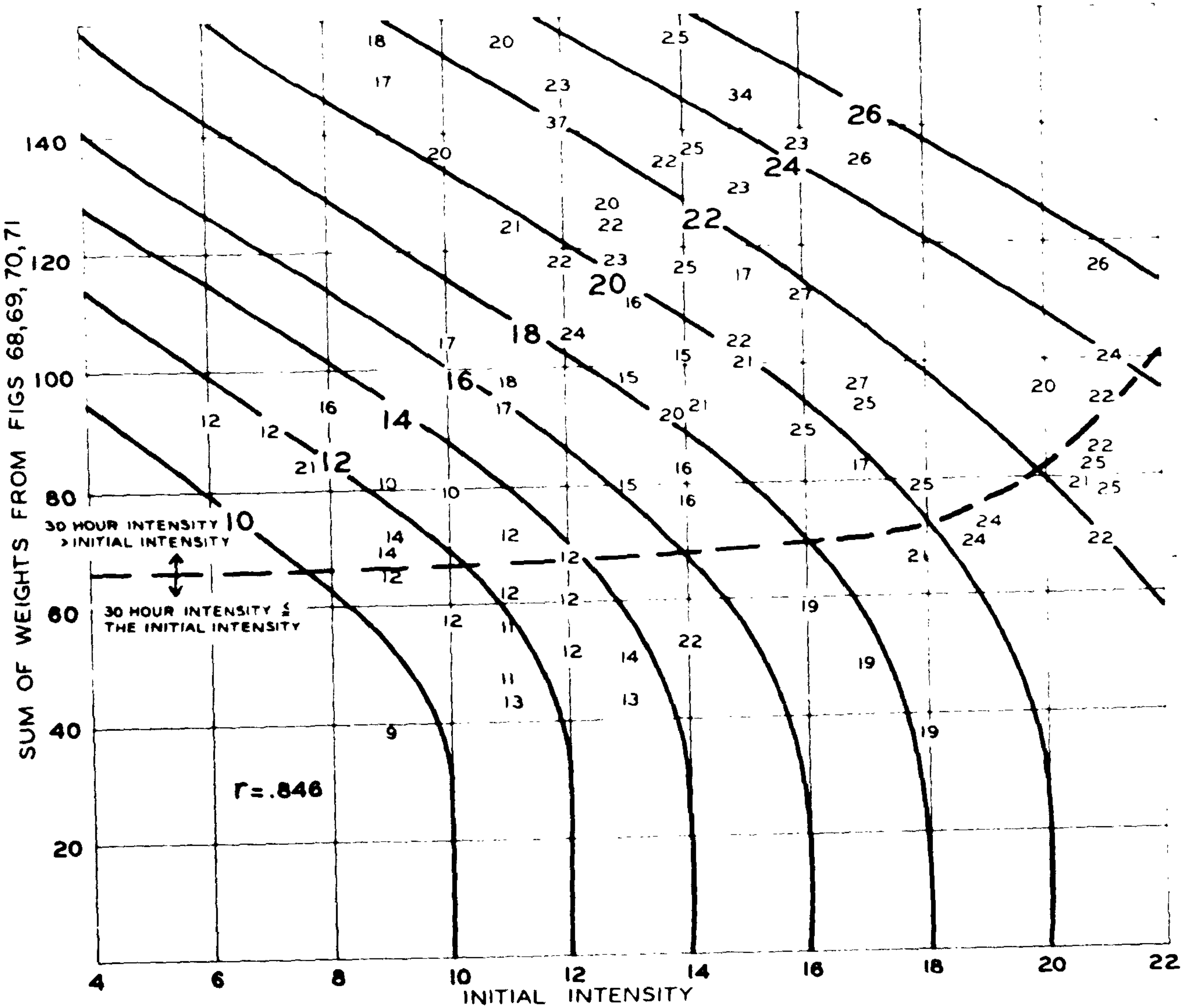

Fig. 72. Intensity forecast, final. The initial intensity is entered along the abscissa. Measure the distance from the surface low position to the 500-mb trough line along the latitude of the low. Then:

a. If the distance is < 800 miles, add the weight values obtained from Figs. 68, 69, 70, and 71 and enter this sum along the ordinate. The plot determines the forecast maximum intensity in the next 30 hours.

b. If the distance is > 800 miles, divide the sum of the weight values obtained from Figs. 68, 69, and 70 by two before adding with the value of Fig. 71. The sum, after performing this operation, is then entered along the ordinate. The plot determines the forecast maximum intensity to be expected in the next 30 hours.

A question must now be raised regarding the movement of the 500-mb trough with respect to the surface system. At times during the winter season, the upper trough associated with the surface system will remain stationary or retrograde while the surface low moves on. In general, this occurs only when the 500-mb trough is a great distance from the surface low; however, in these cases the above method forecasts too much intensification. Therefore, a separate rule has been devised and should be applied when the distance from the low to the 500-mb trough is greater than 800 miles. The forecaster should measure this distance as a standard procedure when computing the 500-mb parameters. The rule is:

> When the east-west distance between the surface low position and the 500-mb trough is greater than 800 miles, the values obtained from the weight lines on the three 500-mb graphs (see Figs. 68, 69, and 70) should be divided by two before summing with the 850-mb advective factor weight value (see Fig. 71) and proceeding to the final graph.

If the forecaster knows for certain that the 500-mb trough will fade or retrograde, it would be advisable to reduce the forecast maximum intensity value a nominal amount. It appears that a few of the "misses" (based on the final graph) were due to to erratic movements of the 500-mb features. Although it is not pertinent to include the prognosis of the upper level troughs at this time, it is certainly necessary that this should be included as a parameter in future research. The independent test data comprising 33 cases during the winter of 1951–52 yielded a correlation coefficient between forecast and observed maximum intensity of .79 with an average error of 2.96 mb. A sample work sheet is provided on page 109 for the use of the forecaster and serves also as a summary of the operations which should be followed in arriving at the deepening or filling prognosis.

1.6. MOVEMENT OF CATEGORY IV CYCLONES

Some conclusions concerning the movement of Category IV cyclones have been made in a preliminary report on this research. Since a number of the readers have seen and applied parts of these preliminary results, it is pertinent to remark that the treatment of the direction of movement has undergone major changes. The parts concerned with speed remain unchanged. Considerable use has again been made of areas of cross-isotherm flow as a forecasting parameter. The reader is again referred to page 93 for a discussion of the method of determining the center A_w.

1.61. *Speed of Movement*

Numerous methods have been described in the literature for predicting the speed of movement of surface cyclones. Expressions can be found such as "Surface lows move with 60 to 80 percent of the 700-mb (or 500-mb) flow over them." In case of difluent contour fields or closed systems over the surface center, the application of these rules becomes difficult. In the process of the investigation, it was found that lows which are far removed from the center A_w generally move faster than the lows which are located near it. This seems to verify the finding of George (1949) that lows have a "preferred position" with respect to the thermal and pressure fields, and that lows which are some distance from the area of indicated warm advection tend to accelerate to a position more favorable for continued cyclogenesis.

The first observation may be stated as follows: the speed of the surface cyclone is roughly proportional to the distance between the low center and A_w. On the basis of the preceding statement, one would assume that the speed of movement of A_w would have an effect on the speed of the surface low centers. It is

WORK SHEET FOR CATEGORY IV CYCLONES

INTENSITY

Date . Time Surface Chart . ... Time Upper Chart

850 700 500

1. From surface chart find intensity count of low. (Average difference in pressure between center of low and the four cardinal directions at points 600 miles from center.)
2. Latitude of the surface low . . . .
3. Trough sharpness. (Difference in height in feet at the latitude of low between a point 1000 miles west of the trough and the trough plus the difference using a similar measurement 1000 miles east.) . . . .
4. Correct (3) for latitude . . . .
5. Maximum temperature gradient 1000 miles in northwest quadrant from surface low . . . .
6. Temperature factor. Difference in temperature at a point 500 miles west and 500 miles east of the trough line, measured along the latitude of the low. The sign is positive if colder air is to the west . . . . .
7. Distance in statute miles from low to trough along latitude of low . . .
8. Determine position of A_c and record latitude of A_c . . . .
9. Construct line perpendicular to the contour flow over A_c and measure height difference 300 miles either side of A_c . . . .
10. Correct (9) for latitude of A_c . . . .
11. Construct line perpendicular to (9) and measure temperature difference at a point 300 miles upstream and 300 miles downstream . . . .
12. Multiply (10) times (11) . . . .
13. Measure distance from low to A_c. (Statute miles) . . . .
14. Measure meridional distance from latitude of low to latitude for A_c . . .
15. Add (13) and (14) . . . .
16. Divide (12) by (15) . . . .
17. Extract values from intensity graphs:
    - (a) Trough sharpness (4) . . . .
    - (b) Temperature 1000 miles northwest quadrant (5) . . . .
    - (c) Temperature factor (6) . . . .
    - (d) If (7) is greater than 800 miles, divide sum of a, b and c by 2 . . . . .
    - (e) Advective factor (16) . . . .
    - (f) Add a, b, c, (or d) and e . . . .
    - (g) Forecast maximum intensity from final graph . . . .

COMPUTATIONS:

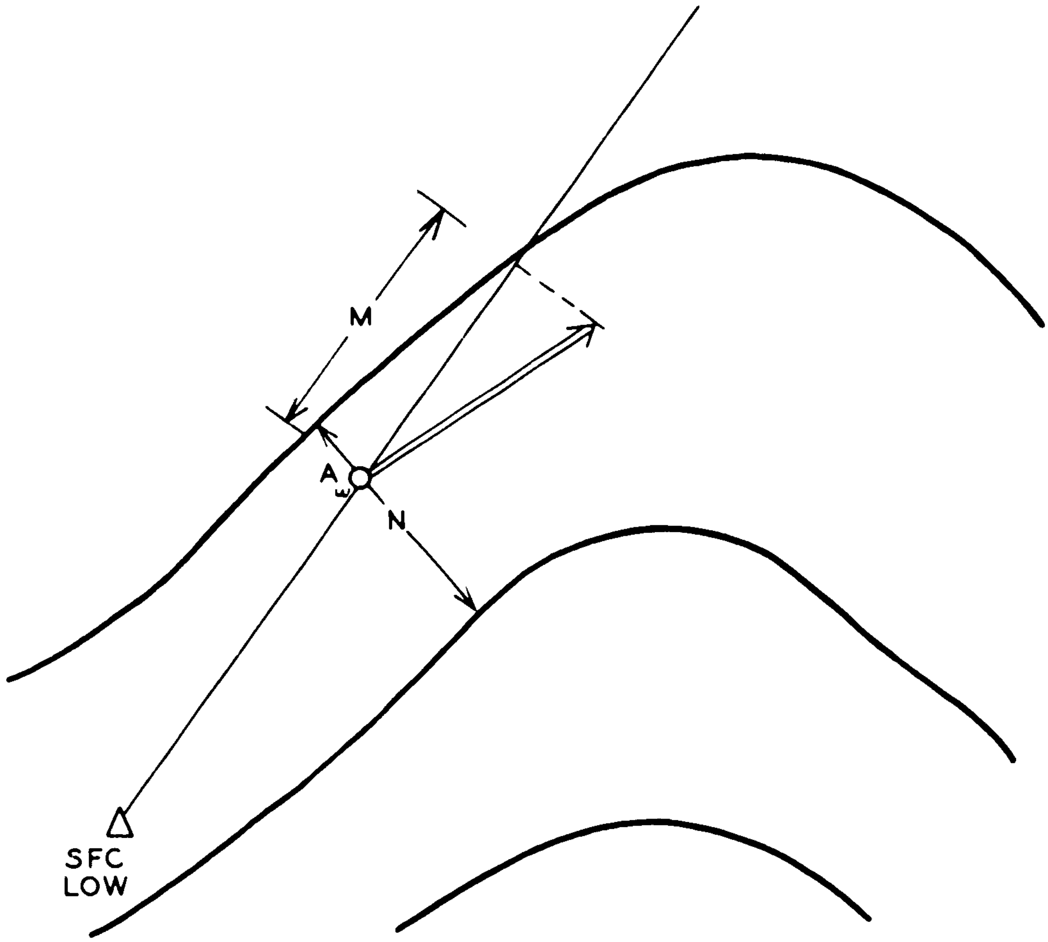

Fig. 73. Wind component. The geostrophic wind measured across the spacing N through A_ω is represented by the double lined vector. The component of this vector on the line from the surface low through A_ω is indicated by the distance M. The most practical measure of this parameter is accomplished by placing the geostrophic wind scale normal to the line from the low to A_ω and noting the wind component (in knots) determined by the "channeling" height lines.

reasonable also to assume that the speed of A_ω is proportional to the rate of flow at A_ω. Further, since the low tends to move toward A_ω, only the component flow along the line from the low to A_ω need be considered.

The second observation is: the speed of the surface cyclone is proportional to the component of flow at A_ω along the line between the low and A_ω. The third factor related to speed is noted by inspection of the thermal field at the 3 lower standard surfaces. When the isotherms are packed along the track, the surface low moves fast and when the temperature field is weak and wandering, they move slowly. The strength of the thermal field is measured exactly as in the previous section on development.

Past efforts to associate the speed of lows with upper winds have been largely unsuccessful (Palmer 1948) because of the necessity for choosing the wind at a particular spot. In many cases, the magnitude of

the wind speed changes radically over fairly short distances and it would be fortuitous if the correct value were chosen. However, in measuring the strength of the temperature field, the magnitude of the thermal wind component is taken into account automatically, giving a measure of air transport over a considerable volume, amounting to an integration of the wind effect.

The third observation is: the speed of the surface cyclone is proportional to the strength of the temperature field.

In summary, the speeds of Category IV cyclones have been shown to be directly proportional to the following:

1. The distance between the cyclone and the center of apparent warm advection (A_w).
2. The strength of flow over A_w.
3. The strength of the thermal field along the track.

1.62. *Objective Forecasting Technique for Predicting Speed*

The first operation is to determine the location of A_w at 850 mb. The distance in statute miles between the surface low and A_w is the first parameter.

The second parameter is the component of the geostrophic wind at A_w in knots along the line from the low to A_w (see Fig. 73). It was found that the most useful measure of this value is the sum of these components at 850 and 700 mb. (For this measurement the position of the 850-mb A_w is marked on the 700-mb chart.) Negative values of this component are counted as zero. This occurs when the position A_w falls within a closed low at either level; it is, however, extremely rare.

The third parameter has already been described in the section on development (p. 99). It is the maximum temperature difference between the position of the surface low and a 1000-mile arc in the northwest quadrant from this position (see Fig. 64). The values at 850, 700, and 500 mb are added together and the sum is used as a parameter.

In summary, the following parameters were selected:

1. The distance in statute miles from the surface low position to the center A_w;
2. The sum of the components of the geostrophic wind in knots on a line connecting the surface low to A_w at 700 and 850 mb.
3. The sum of the maximum temperature difference, in degrees Centigrade, between the surface low position and a 1000-mile arc in the northwest quadrant at 850, 700, and 500 mb.

The objective procedure in determining speed is to enter the values of the above parameters in the multiple correlation given in Figs. 74 and 75. The procedure is:

a. Enter along the ordinate of Fig. 74 the distance, (1) above, and along the abscissa the temperature sum, (2) above.
b. Extract a value determined by the weight lines.
c. Carry value, (b) above, to the ordinate of Fig. 75 and enter along the abscissa the sum of the wind components, (3) above.
d. Read the forecast 30-hour speed in statute miles per hour from the curved lines.

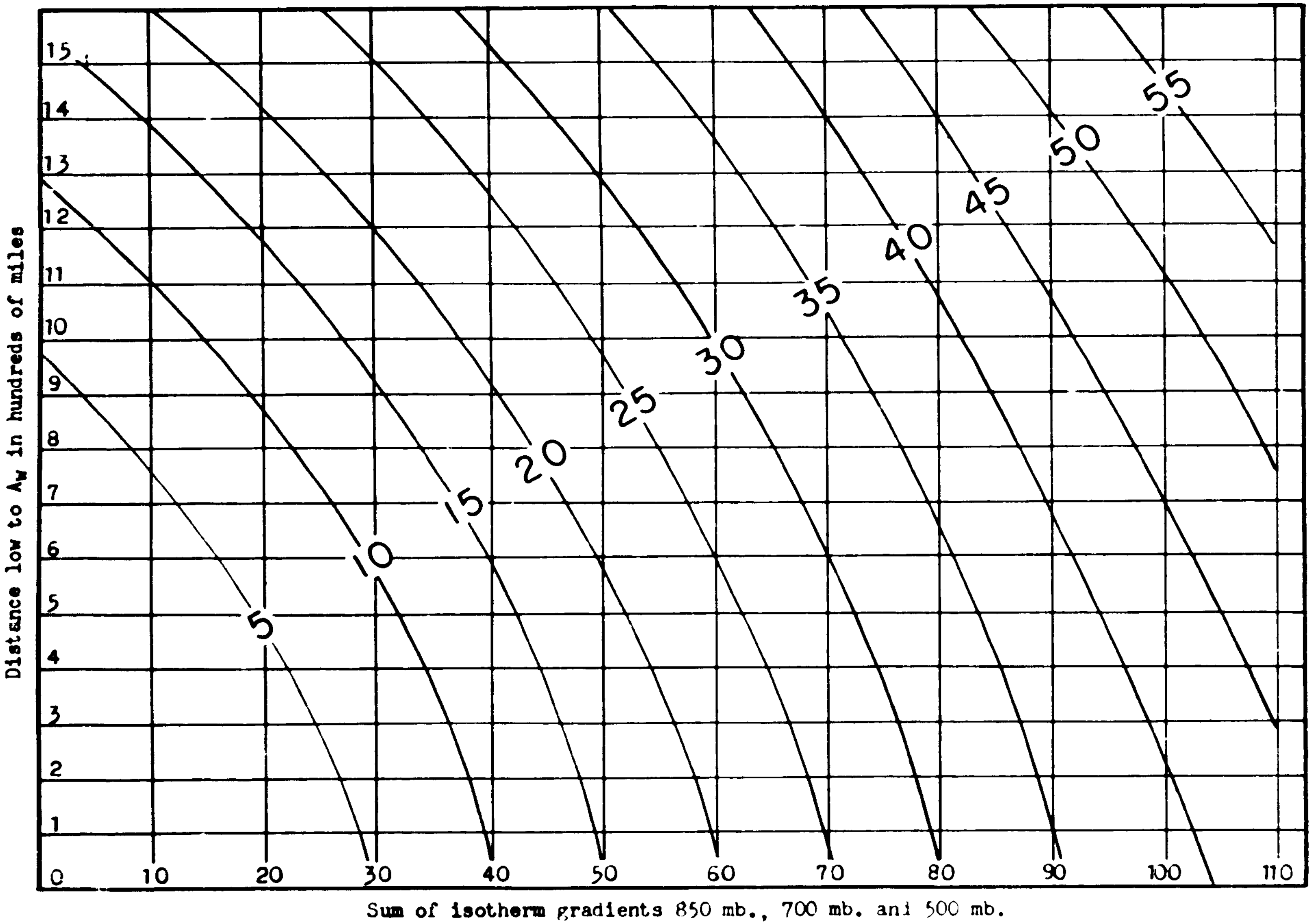

Fig. 74. **Speed forecast, stage 1.** Enter the sum of the temperature measurements at 850 mb, 700 mb and 500 mb (Fig. 64) along the abscissa and the distance between the surface low and A_w on the ordinate. Record the value determined by this plot with respect to the curved weight lines.

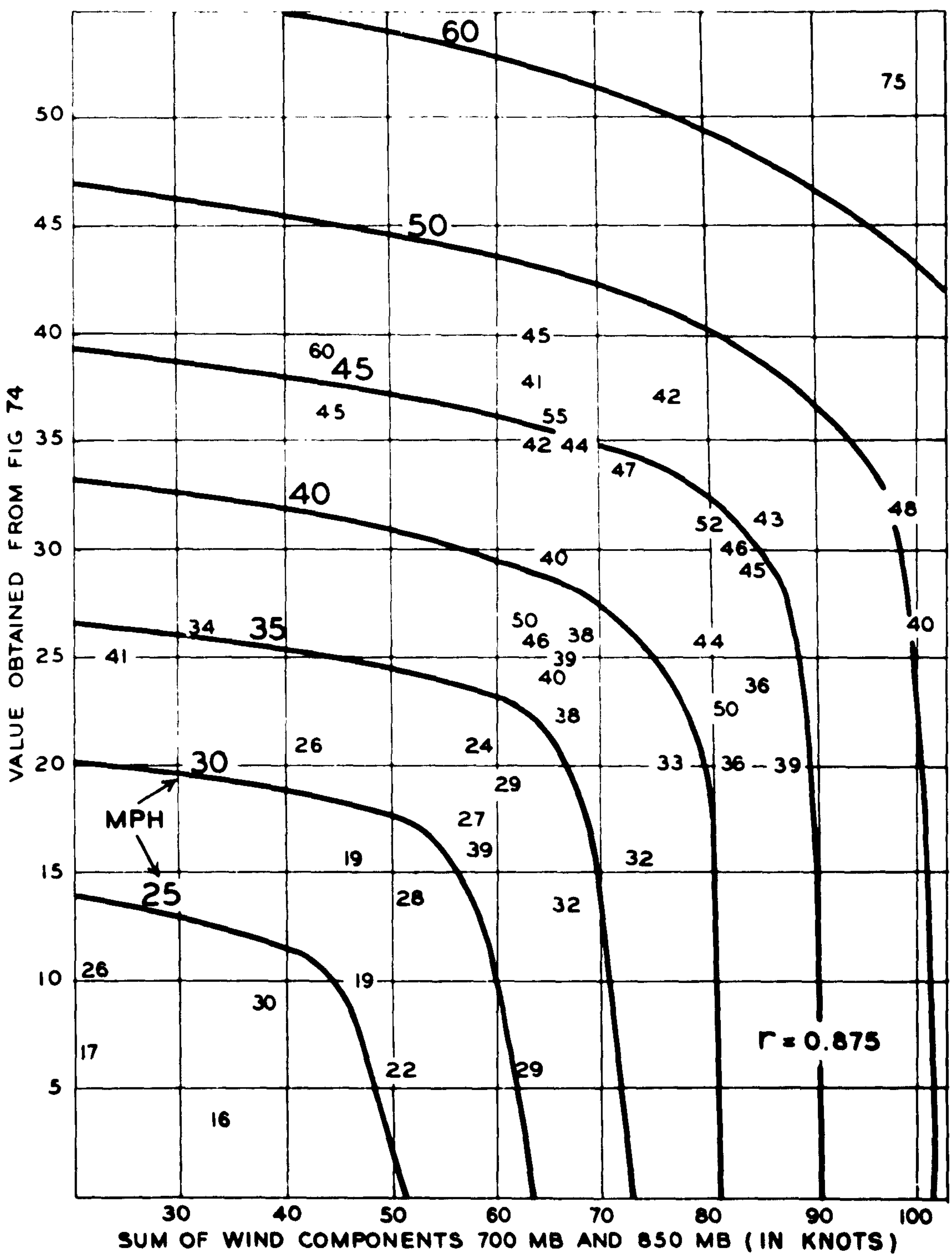

Fig. 75. Speed forecast, final. Enter the weight value determined in Fig. 74 along the ordinate, and the sum of the wind components (Fig. 73) at 850 mb and 700 mb along the abscissa. Read the average 30-hour forecast speed of movement, in miles per hour, from the curved lines. If the storm is a special category cyclone (see text) divide the value determined by this graph by two to obtain the forecast speed.

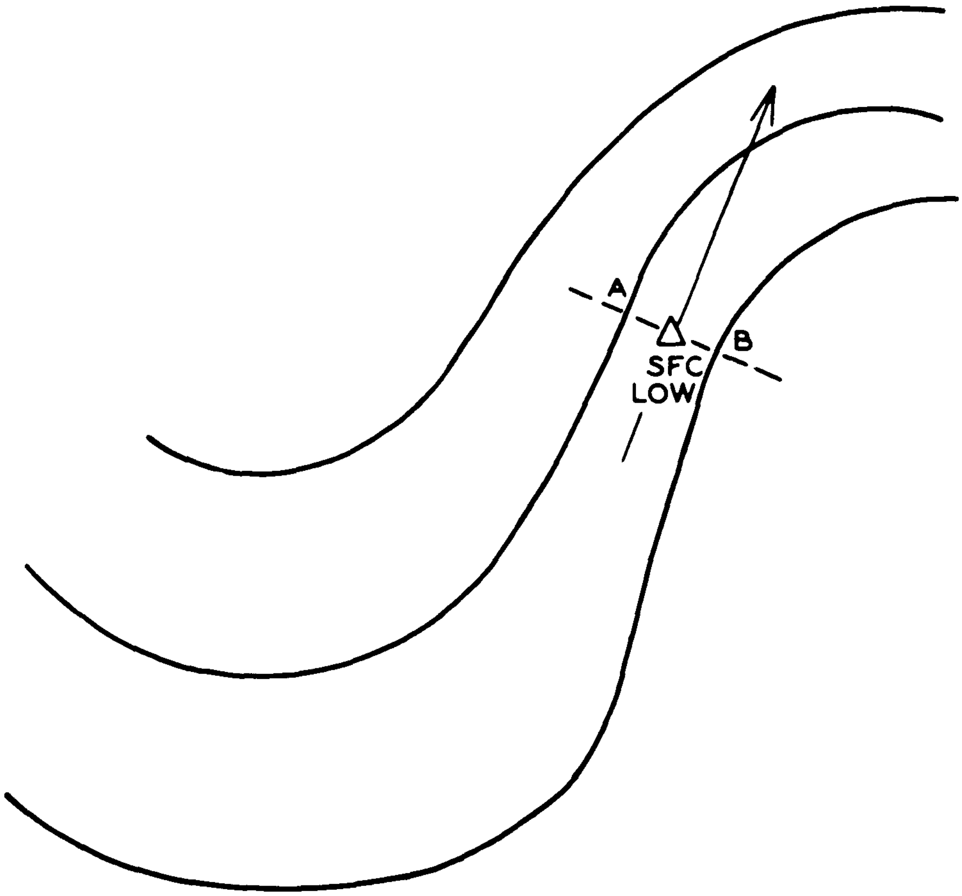

Fig. 76. Instantaneous contour steering. This is generally taken from the 700-mb or 500-mb surfaces, although the technique also applies to the determination of the direction of flow at *A*, which is 850 mb. The instantaneous steering is the average of the directions of the tangential lines at *A* and *B*, the dashed line being normal to the flow.

The solution is not time consuming and the entire operation can be accomplished in 5 to 8 minutes. A worksheet is included on page 115 as a guide for the forecaster.

In previous preliminary reports some explanation was given to a special type of cyclone called a "circling" type of storm. It is felt that this term falsely implies an unusual trajectory and therefore the name has been discarded. These lows will henceforth be termed "Special Category Cyclones" and the forecast modification concerns only the speed of the storm and not the direction. They were also discussed in the section on cyclogenesis.

The special category cyclones are usually of high intensity with both contours and isotherms having large amplitudes. They are defined by the character and strength of the thermal field at 850 mb as follows:

> A special category cyclone has a temperature field such that the amplitude of the 850-mb isotherms is $\geq 13°$ latitude and the half wavelength (east of the thermal trough) is $<$ the amplitude. The "ribbon" of isotherms associated with the cyclone consists of three or more 5-degree isotherms.

WORK SHEET FOR CATEGORY IV CYCLONES

SPEED AND DIRECTION

Date | Time Surface Chart | Time Upper Air

	850	700	500

SPEED:

1. Locate A_0 at 850 mb and transfer point also to 700 .
2. Distance from low to A_0 (statute miles) . . . .
3. Maximum temperature gradient from surface low 1000 miles in northwest quadrant . . . .
4. Add values in (3) .
5. Geostrophic wind component measured in knots along the line from low to A_0 and taken at A_0 . . . . .
6. Add values in (5) . . . .
7. Refer values in 2, 4 and 6 to speed graphs for forecast speed in mph.
8. Check amplitude of isotherms for special category cyclones. (If amplitude is 13 degrees or greater and at least 3 isotherms in ribbon and half wavelength is less, forecast speed should be divided by two.) ..

DIRECTION:

1. Temperature factor (difference in temperature at a point 600 miles west and 600 miles east of the trough line, measured along the latitude of the low. The sign is positive if colder air to the west) .
2. If temperature factor is greater than plus 9, find steering direction over A_0
3. Find instantaneous contour steering over surface low
4. Find steering over surface low (only if 700-mb steering is ill-defined) . . .
5. If (1) above is less than plus 10, use temperature factor direction scale . . .
6. Find average between 2 (or 5) and 3 (or 4). This is forecast direction.

(If steering direction is difficult to determine at 700 and 500 mb and the temperature factor is less than plus 10, the temperature factor direction scale is used as one component and the second component is a line joining the surface low center with the center A_0.)

(If the 850-mb temperature factor is greater than plus 9, use as components a line connecting the surface low and the center A_0 and a line representing the contour flow at A_0. The bisector is the line of future movement.)

VERIFICATION	FORECAST	OBSERVED
SPEED		
DIRECTION		
MAXIMUM INTENSITY		

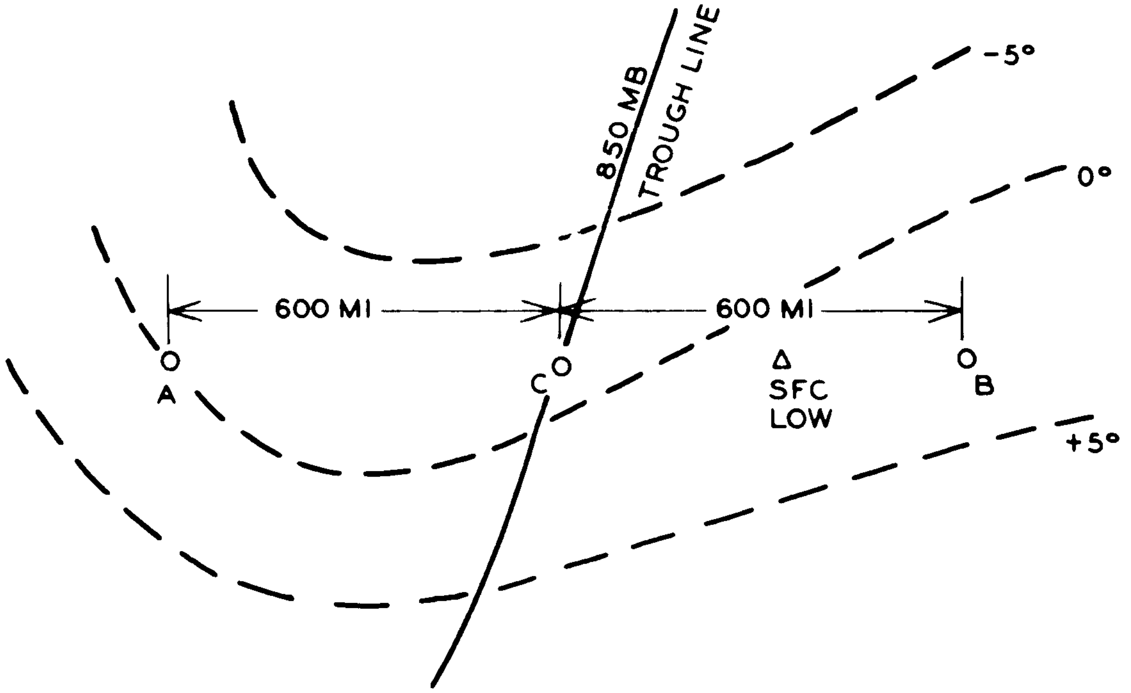

Fig. 77. The 850-mb temperature factor. Measure 600 miles east and west of the 850-mb trough line (C) at the latitude of the surface low. Find the magnitude of the temperature between the point A and point B. The 850-mb temperature factor is this difference prefixed by a positive sign if the colder temperature is at A and a negative sign if B is colder. In the above example, the 850-mb temperature factor is about +3°.

It has been found that the speed forecasts for these storms are generally too high due to the intense packing of the thermal field. This packing contributes mainly to development, producing very intense storms. For this reason, it has been found that when a storm fulfills the requirements of a special category cyclone a value of one-half of the usual forecast speed produces the best results.

1.63. *Direction of Movement*

It has been observed for some time that the instantaneous 700-mb contour steering over the surface cyclone position usually gives a reasonably accurate indication of its future movement. This parameter, shown in Fig. 76, has therefore been integrated into the objective system for all of the Category IV cyclones. There are times, of course, when it is difficult to define the 700-mb contour steering over the surface cyclone due to diffluence of the field aloft or when a closed system at 700 mb is situated over the surface low center. In cases like these, or when there is doubt as to the steering, it is advisable to select the steering direction at 500 mb.

It has also been noted that the orientation of the isotherm field is important with regard to the future track of the surface center. A measurement which partially defines this orientation was introduced in the discussion of deepening and filling. It is the 850-mb temperature factor (see Fig. 77), and since it is a measure of temperatures at equal distances across the trough, the amplitude and wavelength of the isotherms are partially defined. That is, for the short wavelengths this value of the 850-mb temperature factor will be small positive or negative, and for the large wavelengths the values are generally large.

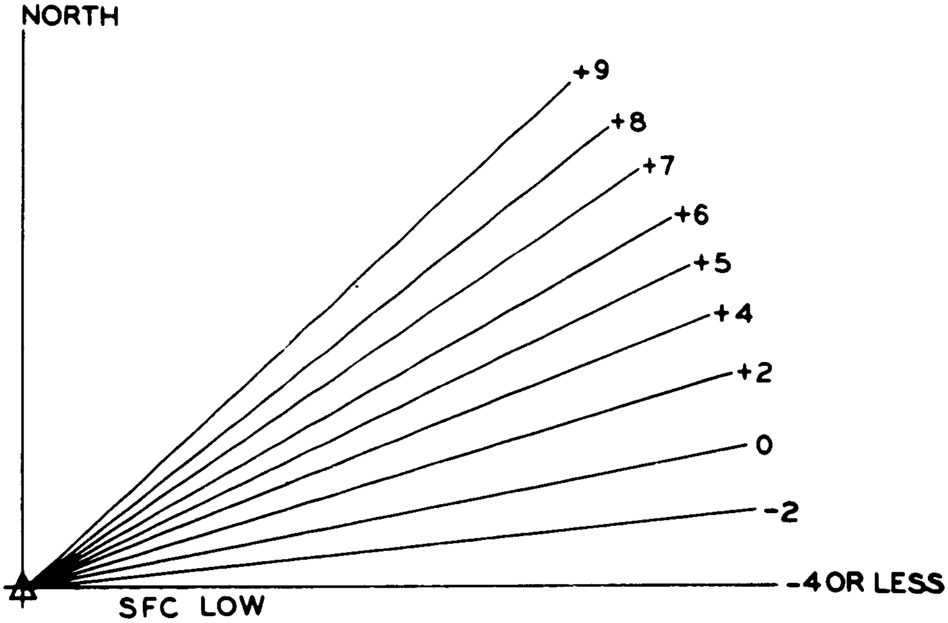

Fig. 78. Template for values of 850-mb temperature factor $< +10$. The center of the template is placed on the surface low position with the vertical axis along the meridian through the low center. The direction value is determined by the line from the low center to the appropriate value of the 850-mb temperature factor on the periphery. The direction values of these lines are given in tabular form on p. 118.

It was found that lows with small positive or negative values of the 850-mb temperature factor tend to have a more dominant easterly component to their track, and cyclones with large positive values had a more northerly component of motion. The value of the 850-mb temperature factor has been combined with the instantaneous 700-mb contour steering over the low center to determine the future direction of movement.

1.64. *Objective Forecasting Technique for Predicting Direction of Movement*

After the value of the 850-mb temperature factor has been determined, the forecaster proceeds according to the magnitude of this value as follows:

1. 850-mb temperature factors $< +10$. Systems of this type generally have a large easterly component. The template, Fig. 78, was designed empirically and values of temperature factors from negative to $+9$ are marked on the periphery of the quadrant. The table in Appendix VI gives the values of these points in degrees east of north and may be used if preferred. The template is placed with the center on the position of the surface low with the 0° line placed along the meridian through the low. A direction is then determined by the center and a point corresponding to the temperature factor marked on the periphery. A line is drawn joining these two points. A second line is drawn through the low center which is the direction of the contour steering at 700 mb over the low center. The angle made by the two lines is bisected and the bisecting line gives the 30-hour direction of movement. An identical answer can be obtained by use of the angle given in the table below.

This angle and the 700-mb steering angle (measured from north) are averaged and the result gives the 30-hour direction of movement.

850-mb Temperature Factor	Direction Value (Degrees From North)
4	90
-2	84
+0	78
+2	74
+4	69
+5	65
+6	61
+7	57
+8	53
+9	49

2. 850-mb temperature factor $\geq +10$. As seen in the earlier section on development, large values of the 850-mb temperature factor generally indicate deepening. These storms have a dominant northerly component. The center A_w is utilized in forecasting the direction of movement of these cyclones. It was stated earlier in the discussion of speed of movement that lows tended to be directed toward the center A_w, and that the movement of A_w has a component in the direction of the flow at A_w. Therefore the low itself will have a component in the direction of the flow at A_w. The direction of contour flow at A_w is measured on the 850-mb chart and is combined with the 700-mb instantaneous steering over the surface low position. The angle determined by these two lines is bisected by a third line which is chosen as the direction of movement. There is one exception to the above procedure. Occasionally A_w will lie in the periphery of a closed low or will be situated such that the flow at that point is west of north. In cases like these, due north should be arbitrarily chosen as the direction of flow over A_w.

1.7. STEERING INDETERMINANT

On some occasions, the steering over the surface low center is indeterminable at both 700 and 500 mb or the direction of flow at A_w is difficult to determine due to difluence or to extremely weak gradients. In these cases, the procedure is identical to that just described except that a line joining the surface low and A_w is substituted for the 700-mb (or 500-mb) steering over the surface low position.

Use of the above methods on 100 cases of dependent data in the winters of 1947-48, 1948-49, 1949-50, 1950-51 yielded a correlation coefficient of .851. The test of independent data consisted of 33 cases during the winter of 1951-52 yielding a correlation coefficient of .72 and an average error of 9.3 degrees. A work-sheet, on page 115 (bottom portion) is included as a guide for the forecaster.

MOVEMENT OF ANTICYCLONES

W. R. BIGGERS

1.1. INTRODUCTION

A tentative solution to the problem of forecasting the future position of anticyclones for 24-and 48-hour periods has been reached. This solution utilizes the isotherm pattern at 850 mb to determine the direction of movement and a maximum wind speed parameter at 700 mb to determine speed of movement. Using independent data, the average error in position was 265 miles for a 24-hour period and 489 miles for a 48-hour period. In this investigation, a total of 87 cases were tabulated for the fifteen winter months (November through March) of 1947 through 1950, for which tracks of at least 48 hours could be obtained.

In investigating the steering of cold anticyclones with the 700-mb flow, George (1949) found the "isotherm ribbon" to be of special significance. Using this as a basis, the cases in the first two years of the sample period were classified according to the position of the surface center relative to the isotherm ribbon at 700 mb and at 850 mb. It developed that the classification relative to the 850-mb isotherm ribbon was rather clear-cut and simple, with 54 out of 59 cases falling into four groups. Tentative solutions to the problem of direction of movement were developed for each of the four types. The resulting methods use the "snapshot" technique on surface, 850- and 700-mb maps; i.e., all prognoses are made from current synoptic material and past positions are not considered.

1.2. MOVEMENT OF ANTICYCLONES

1.21 *Direction of Movement*

Figures 79 through 82 show the four basic classifications of surface high centers relative to the isotherm ribbon at the 850-mb surface. In Type A (Fig. 79), the anticyclone is located in the isotherm ribbon, usually with two or more 5° C isotherms on either side. Type A highs move parallel to the isotherms of this "snapshot picture" for the first 24 hours and slightly toward warmer air during the second 24 hours, so that the path during the 48-hour period is a smooth curve.

In Type B (Fig. 80), the anticyclone is located south of the isotherm ribbon and west of the thermal trough. Its movement is into the isotherm ribbon on a path that is parallel to an extension of the isotherms east of the thermal trough. In most Type B cases it was found that the track for at least the first 24 hours was about perpendicular to the 850-mb contours. This type of high was found to be most common to the Texas-Western Gulf of Mexico area.

Type C highs (Fig. 81) are located north of the isotherm ribbon. The most common synoptic situation for this type is when an anticyclone comes into north central United States from the Manitoba region. The highs move across the isotherms toward warmer air on a path generally parallel to the 850-mb contours but with some tendency to cross toward higher numbered contours. As in Type A, the track is usually a smooth curve throughout the 48-hour period.

In Type D situations (Fig. 82), the anticyclone is located north and east of the isotherm ribbon, with apparent warm advection to the north. A typical example of this configuration occurs with a surface high centered over the plains states, a closed high or strong ridge at 850 mb over the Rocky Mountains, and a closed low at 850 mb over the Mississippi valley southeast of the surface high center. The track of a Type D high is perpendicular to the thermal trough and generally parallel to the 850-mb contour lines.

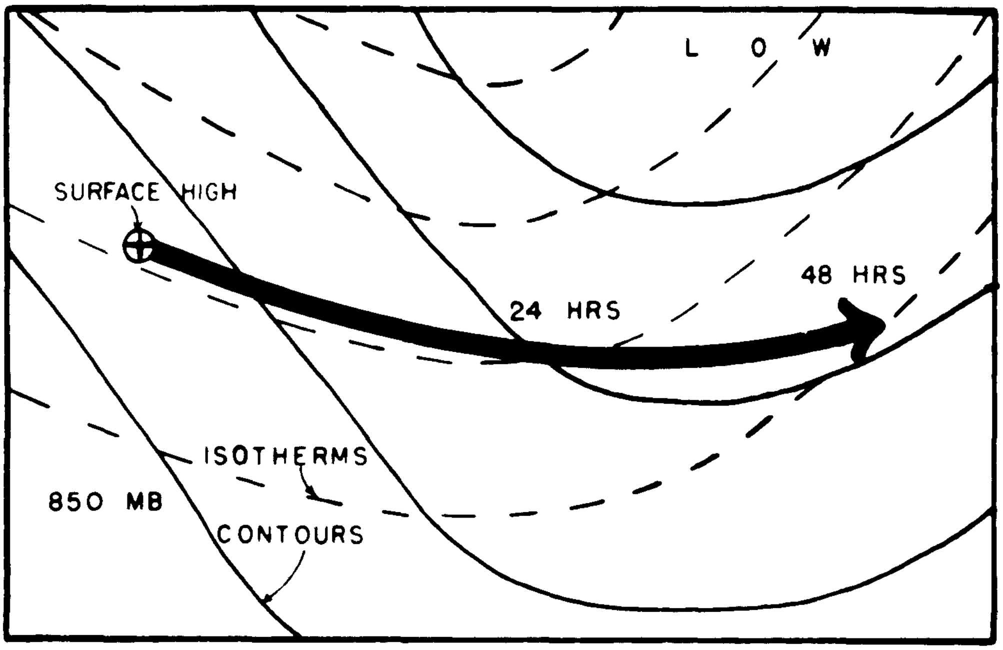

Fig. 79. Type A: Surface high center located beneath the 850-mb isotherm ribbon. It moves parallel to the isotherms for the first 24 hours, with a slight tendency toward warmer air during the second 24 hours.

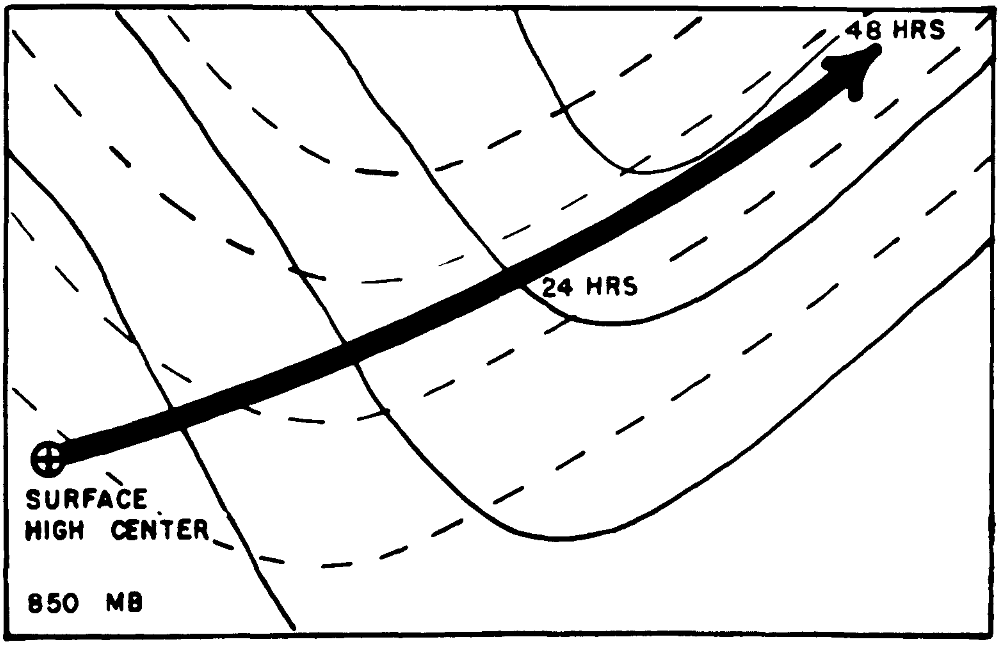

Fig. 80. Type B: Surface high center located south of the 850-mb isotherm ribbon and west of the thermal trough. It moves into the ribbon on a path which is an extension of the isotherms east of the thermal trough.

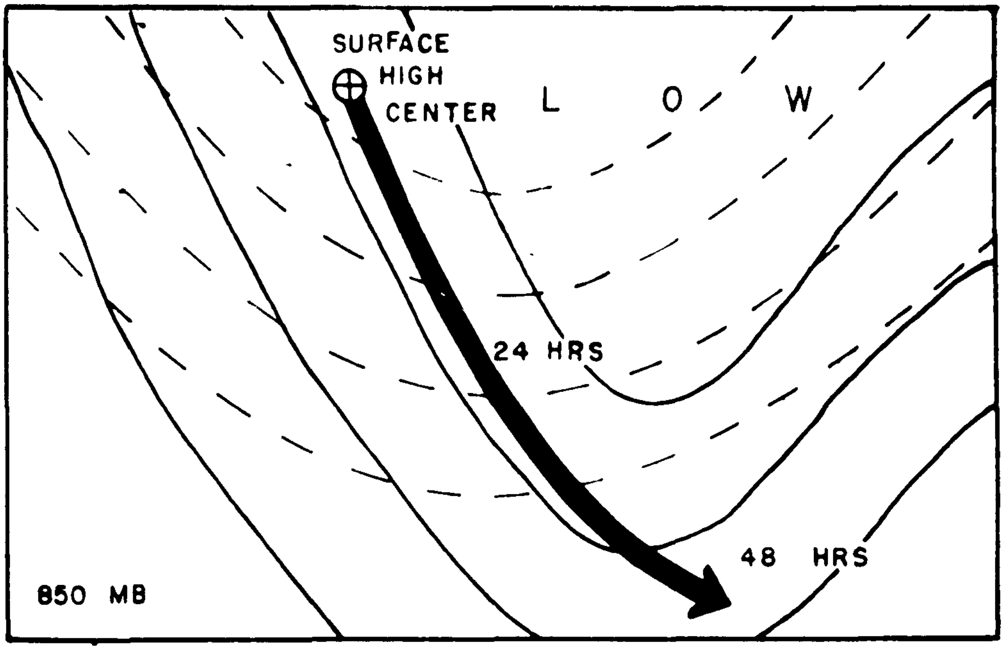

Fig. 81. Type C: Surface high center located north of the 850-mb isotherm ribbon. It moves across the isotherm toward warmer air on a path generally parallel to the contours directly overhead.

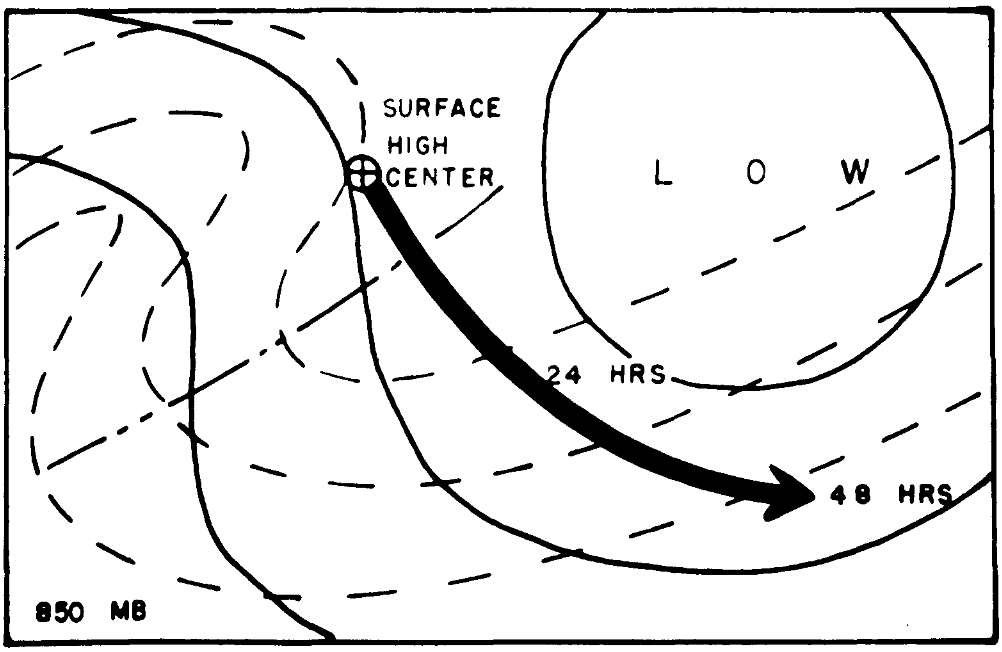

Fig. 82. Type D: Surface high center located north and east of the 850-mb isotherm ribbon. Warm advection is apparent north of center. It moves on a path perpendicular to the thermal trough and approximately parallel to the contour lines.

Two cases were found in which the high center was located under closed isotherms and contours at 850 mb. In both cases, the surface center remained nearly stationery for 48 hours. A few cases were found in which the classification was borderline between Type A and C. In these cases, the track followed was a compromise direction between that of the isotherms and that of the contours.

1.22. *Speed of Movement*

A search for other useful parameters was then initiated. It was apparent that some relation existed between the speed of the high and the flow aloft over or near the high center. A preliminary check was made using the observed wind speeds at 700 mb over the high center. In some cases, this provided a useful measure, but in many others the high moved considerably faster than the observed winds over the center. This led to an examination of the maximum wind speed at 700 mb transverse to the current flow adjacent to the surface high center, and finally to a useful correlation between the maximum observed wind, its distance from the high center and the speed of the high.

Figures 83 and 84 illustrate the method of determining the maximum observed wind speed. The surface position of the high is plotted on the 700-mb chart, and through this point a line is drawn perpendicular to the contour lines. The first definite wind maximum that falls along this line is selected as the value to be used. Figure 83 illustrates the usual case where a maximum of wind speed lies to the north of the high center. The maximum wind in this case is 45 knots. The second parameter, distance from the high center to the point of maximum wind, is 6.2 degrees of latitude. From the graph in Fig. 85, a forecast speed of 31 miles per hour is found for this example. In Fig. 84, the maximum wind speed of 30 knots is measured over the high center (distance 0.0 degrees). From Fig. 85 the forecast speed would be 27 miles per hour. Note that in this example the observed wind speeds decrease as we move away from the high center.

In Fig. 85, the distance from the high center to the point of maximum wind is plotted as the ordinate, and the maximum observed wind as the abscissa. The speed of the highs in mph for 48 hours is plotted beside each point. The distance, for convenience, has been expressed in degrees of latitude, although if desired, a scale of statute miles may easily be substituted.

Where doubt exists as to whether to use a value taken over or near the high center, or a larger value taken some distance away from the high center, check the speed graph (Fig. 85) and use the one that gives the higher forecast speed. If observed winds are not available in an area where the spacing of the contours indicate the maximum to exist, a measured speed may be used, but should be regarded as an estimate.

The following modifications should be applied to the forecast speed:

1. If the high center is within 800 miles of the 850-mb trough line, measured in the direction of expected movement, 10 miles per hour should be subtracted from the forecast speed.
2. If the high center is located beneath a nearly west wind associated with a broad, flat trough at 700 mb, use one-half the forecast speed. (A good test to apply in deciding whether to use this rule is: if it is difficult or impossible to draw a distinct trough line, then the correction should be applied.)
3. In Type C highs situated in Canada or in the northern United States, 15 miles per hour should be added to the forecast speed (from Fig. 85) for the first 24 hours and 5 miles per hour for the second 24 hours.
4. With highs in the Rocky Mountains, roughly west of a line from Big Springs, Texas, to Great Falls, Montana, the speed graph should be used with caution, although it is still the best tool which has been found when used in conjunction with the rule given in the next paragraph.

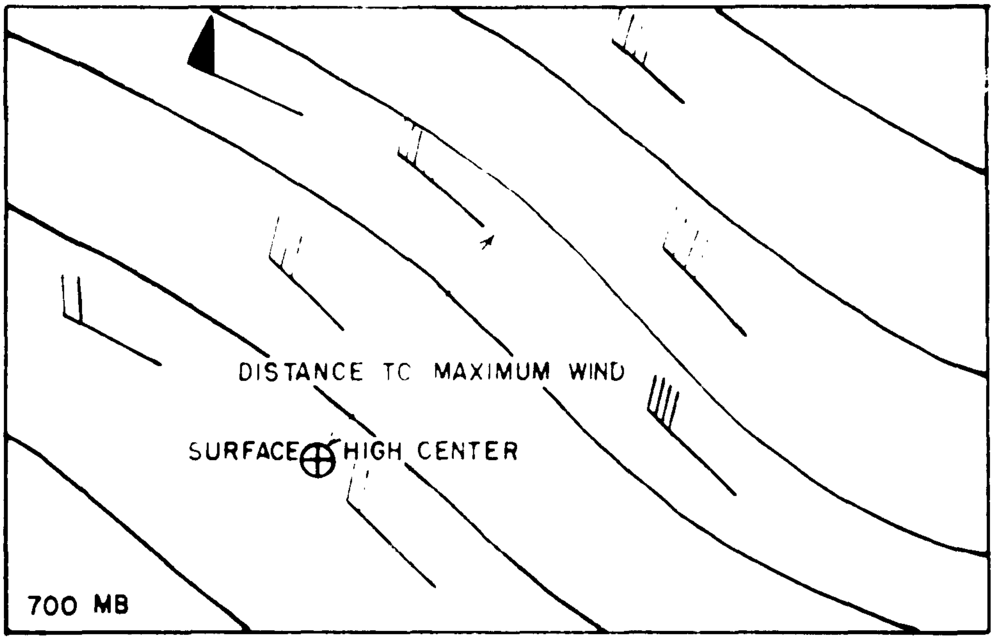

Fig. 83. How the maximum wind and its distance from the anticyclone center is selected.

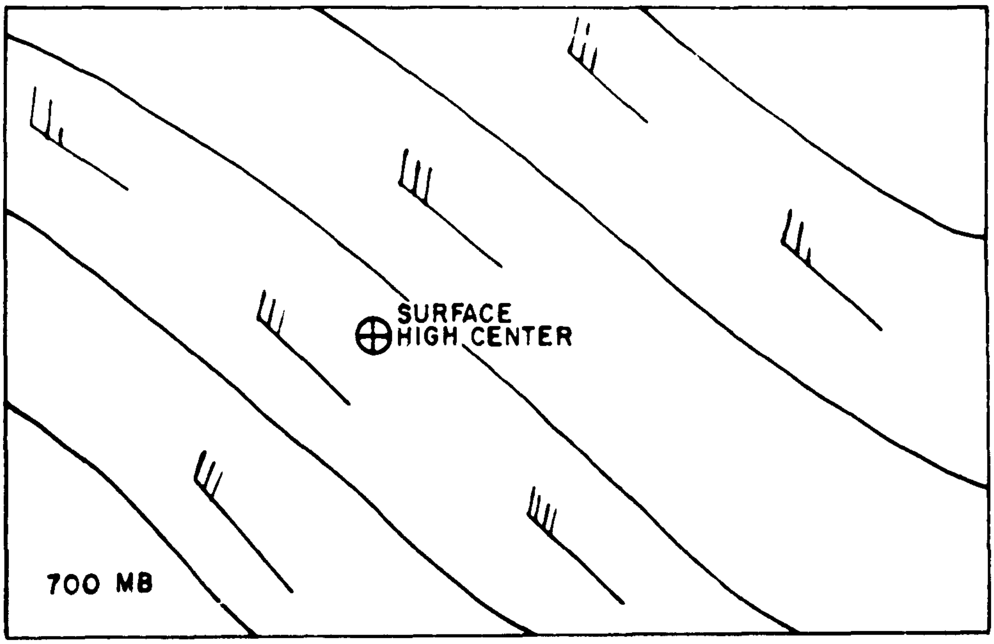

Fig. 84. The case when the maximum wind is selected over the anticyclone center.

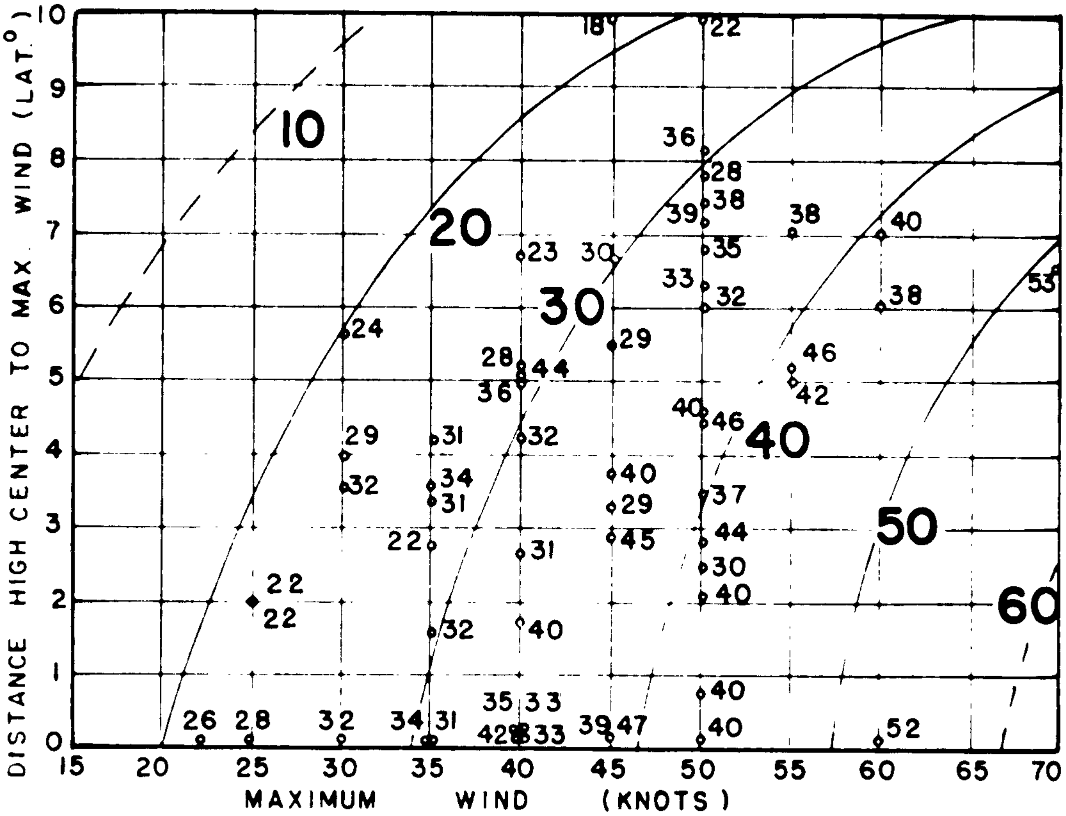

Fig. 85. The relation between the anticyclone center, its distance to the maximum wind in the adjacent current and the maximum velocity. The family of curves measures the subsequent speed of the anticyclone in miles per hour (large figures). Numerals indicate velocities of anticyclones.

The position of the 700-mb trough line proved very useful in forecasting the formation of high centers in the Texas-Oklahoma area following passage of an mP cold front. In a typical example, as the cold front moves off the Texas coast, a ridge from the near-stationary Rocky Mountain high spreads over the area behind the cold front, and remains as a ridge only until the 700-mb trough line moves past the Texas coast into the Gulf. A closed center of two or more isobars then forms in the ridge, and the movement of this center can then be predicted using the methods previously described.

1.3. INDEPENDENT DATA CHECK

Forty-eight cases of anticyclones during the winter of November, 1950 through March, 1951 were used as an independent data check. Distances and speeds were taken on a straight line path from point of origin to the 24-hour position and thence on a straight line to the 48-hour position. In defining the center of a high, the center of symmetry was used. The point of highest pressure could not be used since it was found to shift about from map to map sometimes as much as 200 to 300 miles within the innermost isobar. Tables 4 and 5 summarize the results of this independent check.

Table 4. Frequency distribution of speed errors (mph).

Error	0	1	2	3	4	5	6	7	8	9	10	Over 10
24 Hours	3	3	5	7	6	3	3	2	0	3	2	11
48 Hours	7	6	2	4	2	8	2	0	5	2	2	7

From Table 4, it will be seen that for 24-hour movements, 56 percent of the forecast speeds were 5 miles per hour or less in error, and 77 percent were 10 miles per hour or less in error. For 48-hour movements, 62 percent were 5 miles per hour or less in error, and 85 percent were 10 miles per hour or less in error. It will be noted that the forecast speeds are somewhat more accurate for the 48-hour period than for the 24-hour period. This can perhaps be accounted for by erratic accelerations which are effective during the 24-hour period, but which tend to average out over the 48-hour period.

Table 5. Frequency distribution of position errors.

Error Miles	No. Cases 24 Hours	No. Cases 48 Hours
0-100	11	6
101-200	13	6
201-300	7	2
301-400	4	4
401-500	6	11
501-600	5	2
Over 600	2	15
Average Error	265 Miles	489 Miles

From Table 5, it can be seen that for 24-hour periods, 35 out of 48 cases, or 73 percent were accurate within 100 miles, and that the average position error for the 48 cases was 265 miles. This means that in a majority of cases, the forecast position lies within the innermost closed isobar. For the 48-hour periods, 31 out of 46 cases, or 67 percent are within 600 miles. The correlation coefficient for 48-hour speeds using independent data was 0.63.

DISPLACEMENT OF SURFACE COLD FRONTS

R. M. WHITING

1.1. INTRODUCTION

The dearth of meteorological literature concerning the relation of upper air contour and isotherm patterns to the movement of surface cold fronts indicates less interest in forecasting the positions of cold fronts than in other synoptic developments. This situation undoubtedly has been supported by the feeling among meteorologists that accurate prognoses of cyclogenesis, and of cyclone and anticyclone movements will enable an experienced weather forecaster to determine the future locations of frontal systems. The purpose of the following discussion will be to introduce systematic use of upper air data that will assist in the determination of frontal location on the 30-hour prognostic surface chart.

The system developed in this investigation predicts the average movement of various points on a front for a 30-hour period. Short term accelerations make utilization of the system for periods shorter than 18 to 24 hours questionable. The discussion is divided into three groups based on frontal orientation and geographical location as follows:

1. Fronts or portions of fronts oriented north of 70 degrees.
2. The Great Plains wedge-front.
3. The east coast wedge-front.

1.2. METHOD

The criteria for the first type of cold front are listed below.

1. The portion of the front under consideration must be oriented north of 70 degrees.
2. The trough associated with the surface cold front should have surface isobars indicating a west to east transport of air.

There have been in existence for some time certain qualitative concepts relating upper air flow to subsequent movement of surface cold fronts of type one. Perhaps the most prevalent concept concerns the orientation of the surface front relative to the flow at 700 mb and asserts that a moving surface cold front must have a component of flow at 700 mb directed normal to it. A thorough exploration of the above concept at the 850-mb, 700-mb, and 500-mb levels indicated a strong correlation between the component of flow normal to the front and the ensuing 30-hour frontal movement. This was especially true when considering the 850-mb and 700-mb flow patterns and the most consistent results were obtained from the 700-mb charts. It was also noticed that the orientation of the isotherms at the 700-mb level relative to the surface cold front was important and that frontal movement depended on the thermal gradient along the front. These observations led to the following rule: future movement of a surface cold front is directly proportional to the geostrophic flow and thermal wind component directed normal to the surface front at the 700-mb level. See Figs. 86, 87.

The preceding rule was formulated after considerable subjective analysis of composite slow and rapid moving frontal situations. The next step was the transfer of these subjective observations into objective measurements which could be used to obtain a quantitative estimate of future frontal displacement. To accomplish this, the following precedure was devised:

Step One. The exact surface frontal position was transferred to the 700-mb chart.

Step Two. Various points (called frontal reference points) on the surface front were selected, usually midway between the intersection of the contours with the surface front.

Step Three. The 700-mb geostrophic components normal to the front over the frontal reference points were measured.

Step Four. The thermal gradient components along the front were measured at the frontal reference points by proceeding northeast along the front to a point 2° C colder than the reference point and southwest along the front to a point 2° C warmer. The distance between these two points was directly measured in statute miles and will be referred to as the thermal distance. When the thermal distance was 1500 miles or greater, or when colder air was encountered southwest of the frontal reference point, the thermal distance term was automatically assigned a value of 1500 miles.

The above procedure outlines the basic parameters developed, and the methods by which they were obtained. The attempt to correlate the geostrophic and thermal parameters through the medium of the scatter diagram produced excellent results for all cases in which the geostrophic parameter was 50 knots or less; however the response of surface fronts to geostrophic components greater than 50 knots was poor. This fact necessitated a review of the latter data which led to the discovery that sustained movement of a surface cold front over a 30-hour period in excess of 40 miles per hour was a meteorological oddity. In addition, it was noted that strong gradients at the 700-mb level usually produce forecasting errors even when the geostrophic component normal to the front is less than 50 knots. The geostrophic flow at 700 mb may be separated into components normal to and parallel to the surface front. It was assumed that large geostrophic components *parallel* to the surface front acted as a deterrent to frontal movement due to the tendency for minor waves to form. For these reasons, the geostrophic flow normal to a front could not be used as a parameter without modification.

Figures 88 and 89 represent graphical solutions for determining the speed of a frontal reference point along a line normal to the front. Figure 88 gives a modified geostrophic component which is used as the abscissa in Fig. 89, which in turn, gives the speed of the frontal reference point. In an effort to improve the results of Fig. 89, parameters of advection and of wavelength and amplitude were investigated at the 850-, 700-, and 500-mb levels; however it was found that their use did not produce any improvement so they were discarded.

Details concerning the data used and the accuracy of Fig. 89 are given below.

1. One hundred eighty-six frontal computations comprise the total data sample for the period November 1950 through March 1952.
2. Fifty-three computations for the period November 1950 through March 1951 are independent data.
3. The correlation coefficient between the observed and forecast speeds (using Fig. 89) of frontal reference points for the independent data is .86.
4. The average error in the forecast speeds for the independent data is 3.7 miles per hour.
5. The maximum error in the independent data is 12 miles per hour.
6. A frequency distribution of errors in average speed for 30-hour period for 3 mph increments is listed below for the independent data.

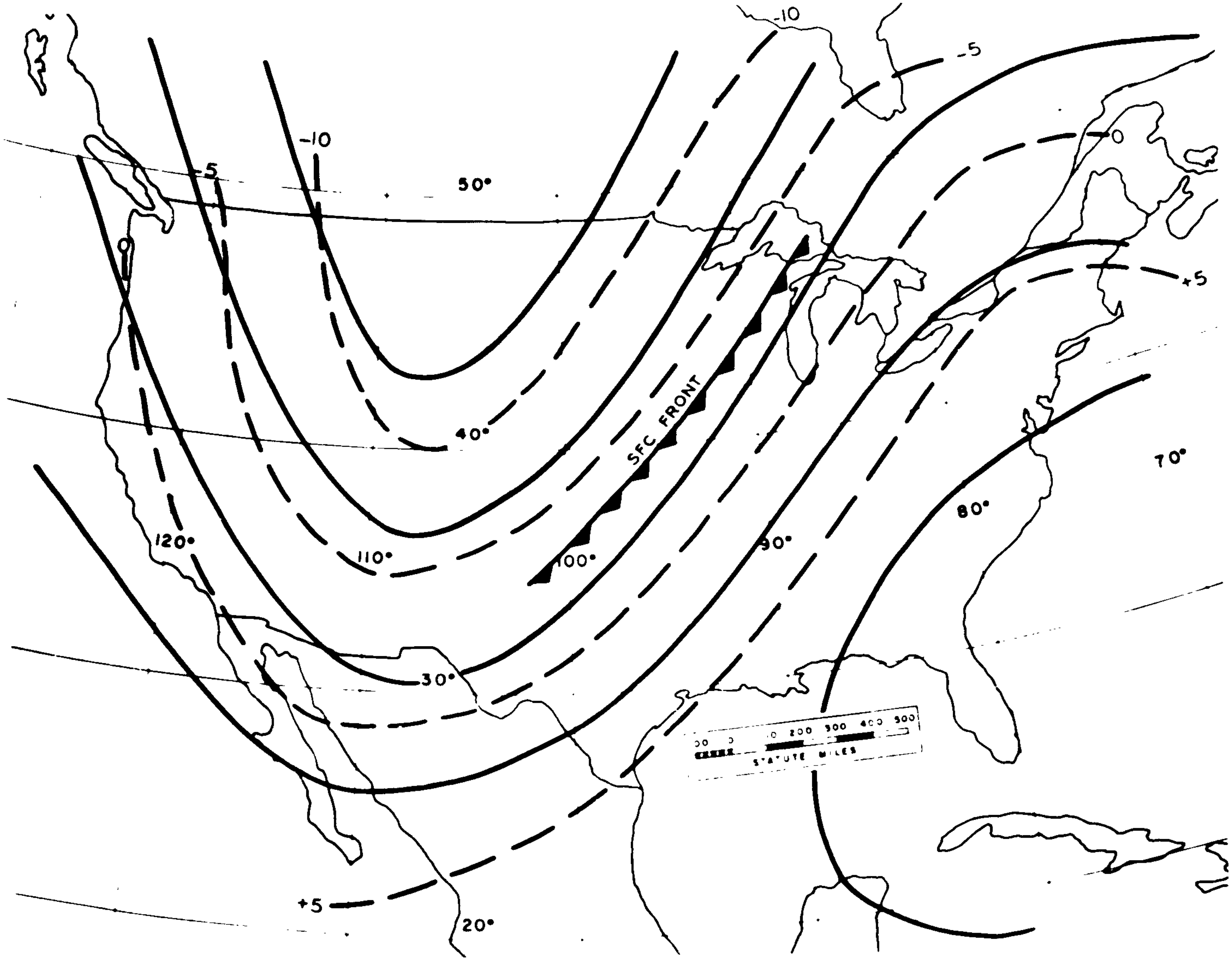

Fig. 86. Typical 700-mb contour and isotherm pattern relative to a slow-moving surface cold front. The solid lines are the 200-feet height contours. The dashed lines are 5° isotherms.

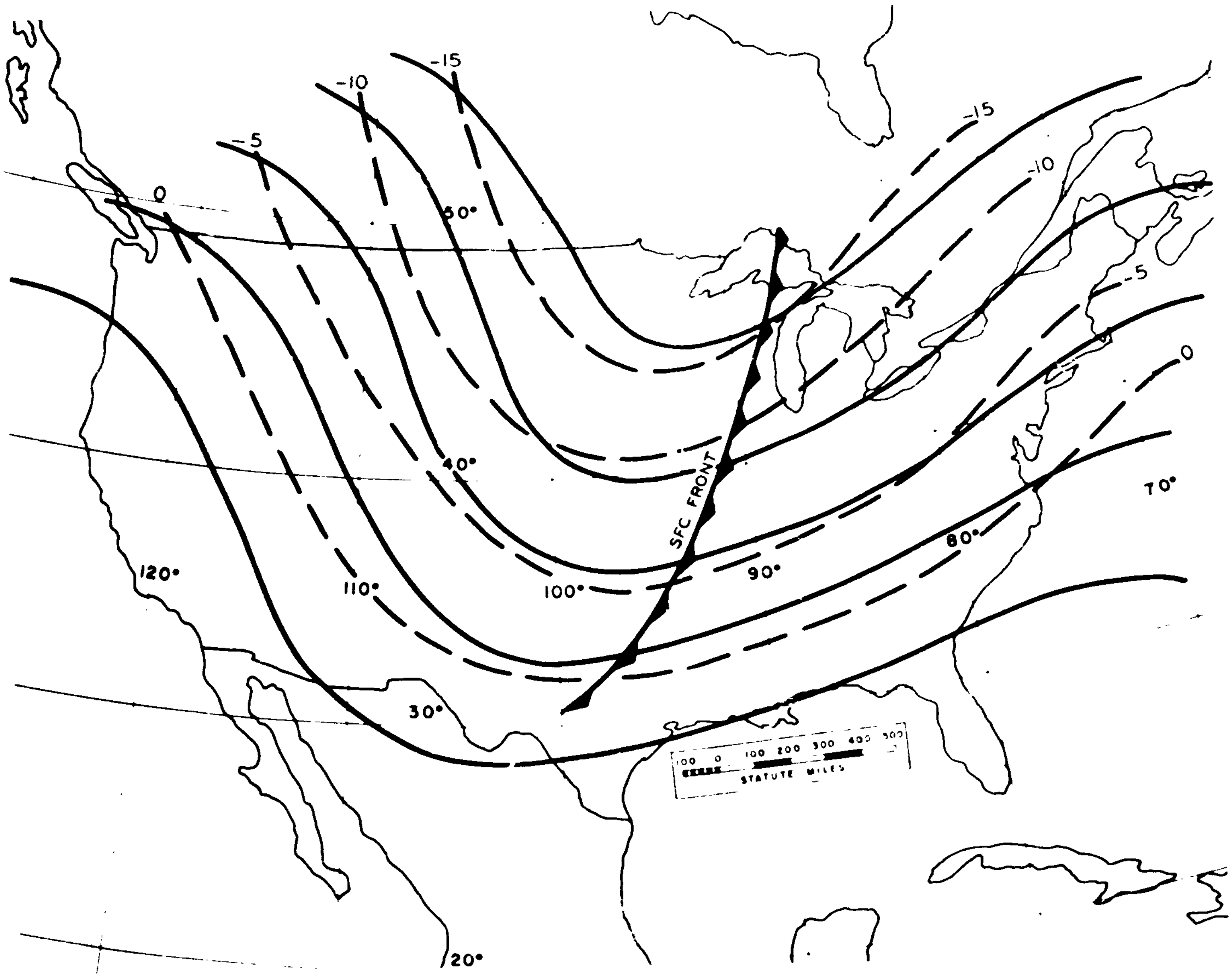

Fig. 87. Typical 700-mb contour and isotherm pattern relative to a rapid-moving surface cold front. The solid lines are 200-foot height contours. The dashed lines are 5° isotherms.

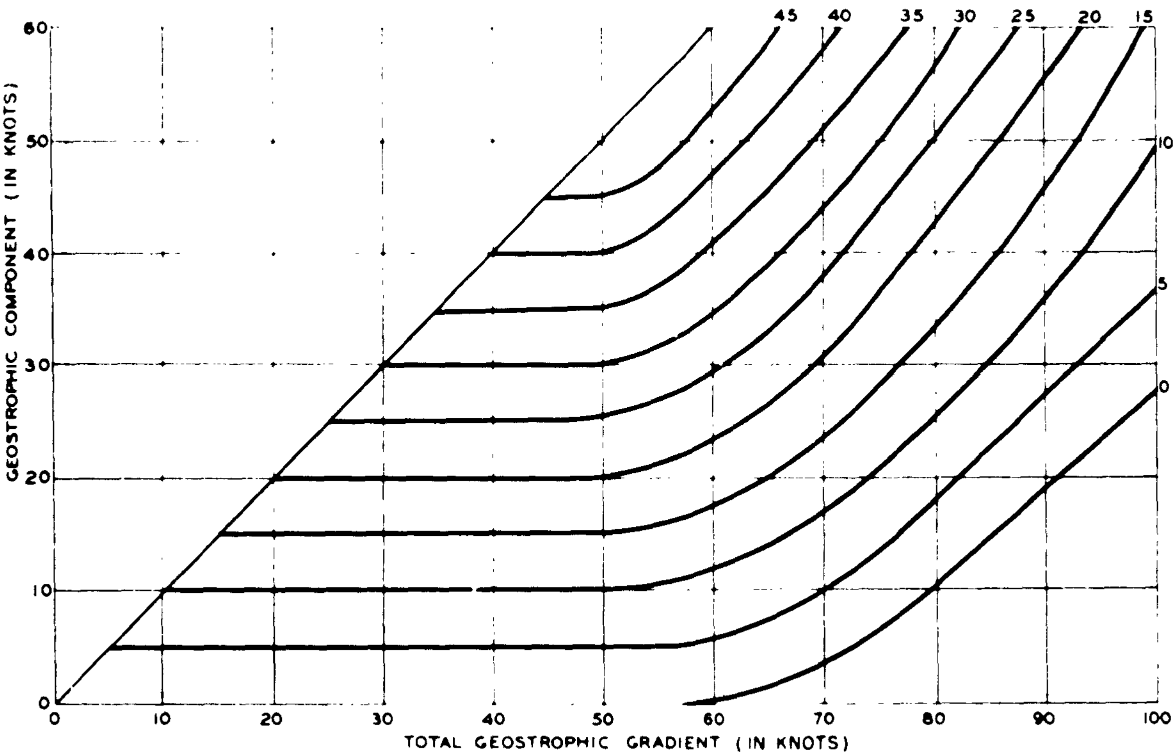

Fig. 88. A modified geostrophic component normal to the surface front at 700 mb. The ordinate is the geostrophic component normal to the frontal reference point at 700 mb in 10-knot increments. The abscissa is the total geostrophic gradient over the frontal reference point in 10-knot increments. Carry the value obtained from the graph to Fig. 89.

Table 6. Frequency distribution of errors.

Error mph 30 Hrs	No. Cases	Percent
0-2	22	41 5
3-5	18	33 9
6-8	9	16 9
9-11	3	5.6
12-14	1	1 8

An example of the procedures is given using Fig. 90 on which the necessary data are listed.

Step One. Measure gradients at each of three frontal reference points A, B, C.

Step Two. Measure geostrophic components normal to front over frontal reference points.

Step Three. From each of the three frontal reference points proceed along the front to points 2° C colder and 2° C warmer. The distance in statute miles between these two points is the thermal distance.

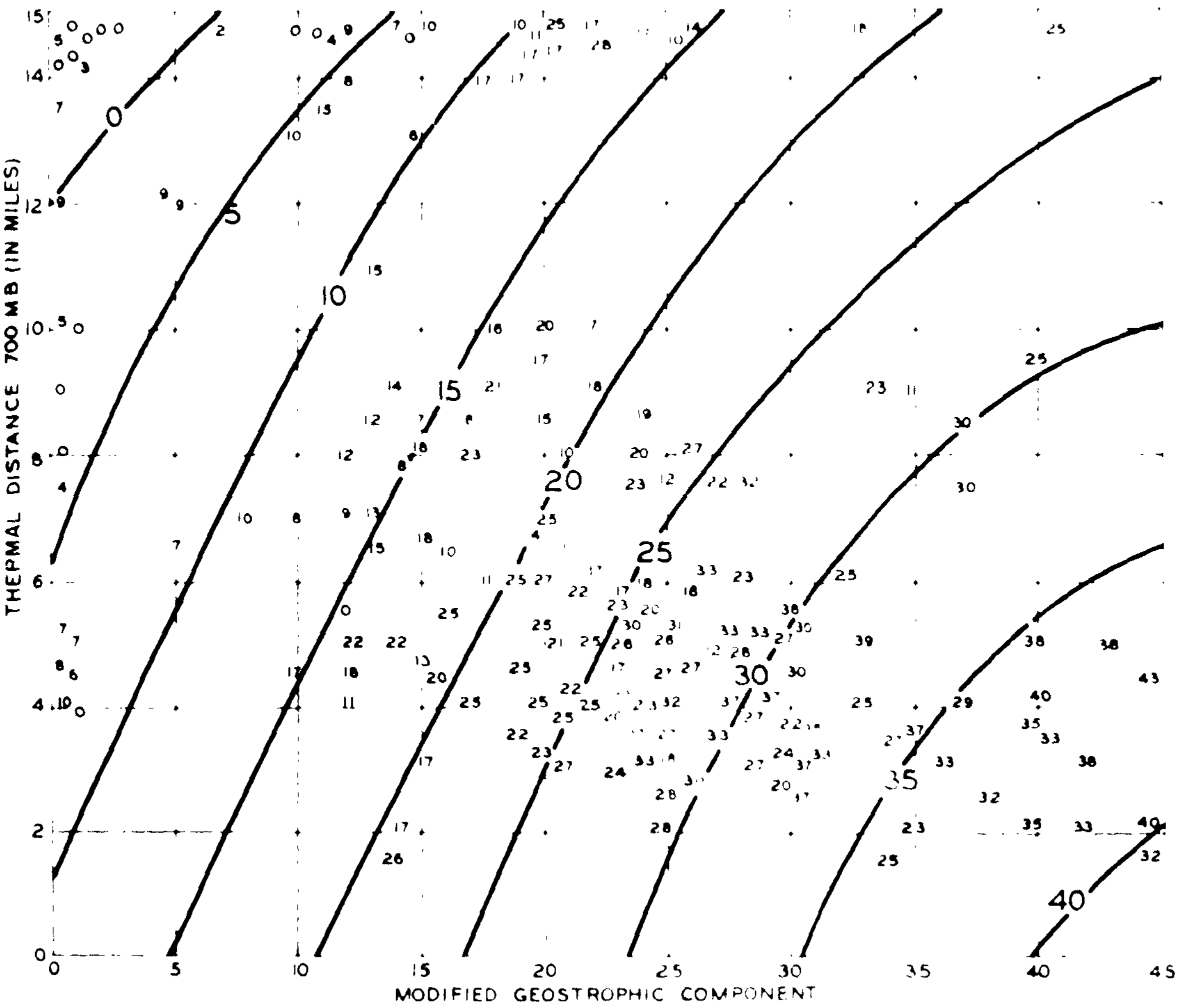

Fig. 89. The final forecast speed for 30 hours of a frontal reference point in miles per hour along a line normal to the front through the frontal reference point. The ordinate is the thermal distance term in increments of 200 miles. The abscissa is the modified geostrophic component normal to the surface front obtained in Fig. 88.

Step Four. Enter Fig. 88 with the total geostrophic component and the geostrophic component normal to the front. The reselt is the modified geostrophic component normal to the front.

Step Five. Enter Fig. 89 with the modified geostrophic component as the abscissa and the thermal distance as the ordinate.

Step Six. Move each frontal reference point for 30 hours at the speed indicated from Fig. 89 along a line normal to the front.

Step Seven. Connect the projected frontal reference points to construct the prognostic frontal position.

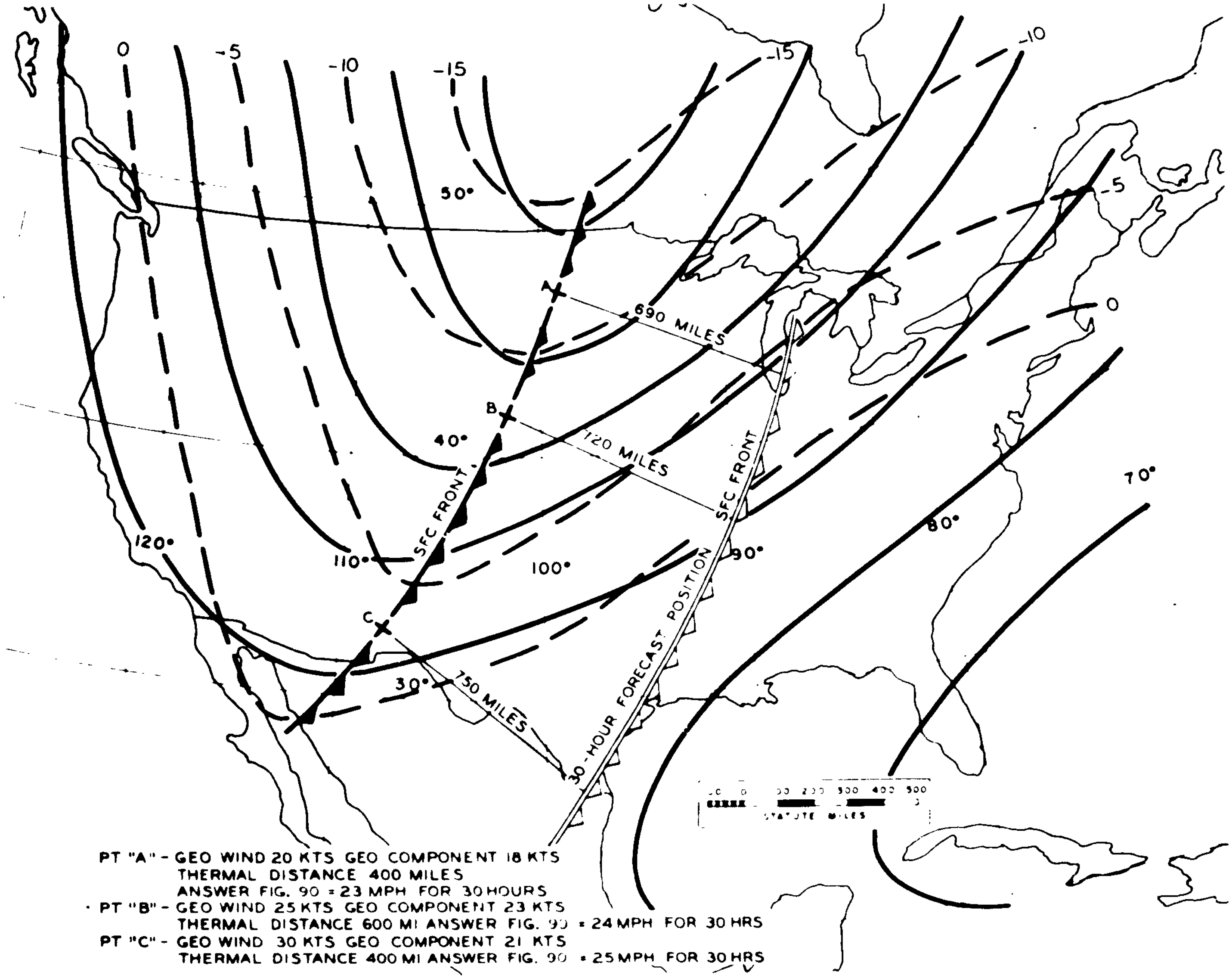

Fig. 90. Example of Category I computation for 30-hour cold frontal displacement. Solid lines are 200 ft contours. Dashed lines are 5-degree isotherms. See page 127.

The use of the preceding technique will naturally give the best results when coordinated with the material developed in other portions of this publication concerning cyclogenesis and the movement of cyclones and anticyclones. Therefore, the importance of cyclogenesis and cyclone movement to forecasting frontal locations is discussed below for six cases.

1. Numerous situations arise where the length of the cold frontal structure is small and stretching of the frontal surface occurs during the 30-hour forecast period due to the movement of a low center. In these cases the short length of the cold front usually permits only one frontal reference point computation; therefore the forecast position of the low center determines the northern location of the front and interpolation between the two forecast positions will be necessary.

2. Cyclogenesis on a surface cold front will generally result in deceleration during the period that cyclogenesis is taking place. It is therefore suggested that frontal locations obtained by the foregoing method (steps 1 through 7) be modified by considering the predicted location of secondary low centers.

3. When the principal trough at 700 mb lies well to the east of the surface cold front so that the front is under straight northwest flow at 700 mb, frontolysis generally occurs and the front moves at approximately $^3/_4$ of the speed indicated in Fig. 89.

4. When a surface cold front with nearly east-west orientation is in the midwestern United States under westerly flow at 700 mb, the front should be projected until it becomes parallel to the existing flow at 700 mb. Further movement will not take place.

5. When a surface cold front is dominated or controlled by a trough in east-to-west flow, i.e., this portion of the front with inverted isobars is longer than the portion of the front associated with a normal trough, the frontal system will move with approximately half the speed indicated in Fig. 89. There will be a tendency for frontolysis to occur north of the last inverted surface isobar and for a squall line or induced trough to form in approximately 18 hours at a distance ahead of the original cold frontal position given by the full speed indicated in Fig. 89.

6. Fronts which form in troughs to the lee of the Rocky Mountains usually cannot be successfully treated with this system until the major portion of the front has moved east of the 95th meridian.

A sample worksheet is presented for practical application of this technique (on p. 134).

The second type of cold front is called "the Great Plains wedge-front." These fronts are oriented nearly east-west and their movements cannot be predicted satisfactorily by the method devised for the fronts of type one. Their southward progress in the Great Plains and Texas areas is due principally to the "wedging action" of the cold air which blows toward the Rocky Mountains as it circulates around the southern extremity of a high pressure area to the north. In the usual synoptic situation of this type, a cyclone is located east of the 90th meridian and the cold front becomes nearly east-west as it crosses the 100th meridian. The surface trough in this area will usually be inverted with east to west flow through the trough and easterly winds north of the front. Normally the movement of the portion of the front east of the 95th meridian may be computed through the methods used for fronts of type one.

WORK SHEET FOR CATEGORY I COLD FRONT

DATE: . . . .

TIME OF 700-mb CHART: . . . .

REQUIREMENTS:

1. Front or portion of front under consideration must be oriented north of 70 degrees. Wedging action to the windward of a mountain barrier should not be a factor in the frontal movement.
2. Do not apply this technique to surface cold fronts that have formed in the trough to the lee of the Rocky Mountains until the major portion of the front has passed east of the 95th meridian.

DEVELOPMENT:

1. Sketch surface cold front on the 700-mb chart.
2. Select frontal reference points on the front preferably between the contour-front intersections. Note the latitude of each frontal reference point
3. Measure the total geostrophic wind at 700 mb over each frontal reference point . . . .
4. Measure the geostrophic component normal to the front as determined by the contour front intersections . . . .
5. Enter Fig. 88 with the values obtained from operations 3 and 4. This is the value of the modified component normal to the front .
6. From each frontal reference point proceed along the front 2° C toward colder air to the northeast and 2° towards warmer air to the southwest. Measure the distance between the two temperature points in statute miles to obtain the thermal distance term. If the thermal distance is 1500 miles or greater or if colder air is encountered when proceeding to the southwest of a frontal reference point, assign 1500 miles to the thermal distance term
7. With the values obtained from operations 5 and 6, enter Fig. 89 for a final forecast speed. In statute miles per hour for 30 hours . . . .
8. Move each frontal reference point with the speed indicated from Fig. 89 for 30 hours along a line normal to the front through the frontal reference point.
9. Connect all projected frontal reference points. Connect the northernmost reference point to the predicted low center position. The line constructed is the 30-hour prognostic cold front position.

MODIFICATIONS:

1. If the surface front lies well to the west of the principal trough at 700 mb and is under northwest flow at 700 mb, frontolysis is likely. Move the front with 75 percent of the speed indicated from Fig. 89.
2. If the portion of the surface front controlled by an inverted surface trough, east to west flow through the trough indicated by the surface isobars, is greater than the portion of the front controlled by a normal trough, move the front at 50 percent of the speed indicated from Fig. 89.
   - A. There will be a tendency for frontolysis north of the last inverted surface isobar, with a squall line or induced trough forming in approximately 18 hours at a location fixed by the full speed of the original frontal computation from Fig. 89.
3. In the event that a near east-west front exists through the middlewestern portion of the United States under west flow at 700 mb, the surface front should be projected until it becomes parallel to the existing flow at 700 mb. At this point further progress will practically cease.

In the pr[illegible] wedge-front with the 100th meridian will be referred to as the [illegible] will give the southward displacement of the front for 30 hours [illegible] Dakota, and Vera Cruz, Mexico. This line was chosen in order to [illegible] Texas and Mexican coasts and to avoid the mountainous areas of Mexico.

The statement[illegible] to explain the mechanics of wedging action in the Great Plains area, but to relate [illegible] synoptic conditions of the upper air to subsequent frontal displacements for a 30-hour period.

1. Northerly flow at 850 mb, as indicated by the height contours over the wedging surface (cold front), results in rapid southward progress of the front during the entire period.

2. Southerly flow at 850 mb, as indicated by the height contours, indicates slow movement of the wedge front.

3. The direction of flow at 850 mb is much more closely related to the frontal movement than the strength of the flow.

4. Cold advection at 700 mb to the northwest of the frontal reference point intensifies the wedging action. Warm advection in the same area discourages the wedging action.

Four basic flow patterns at 850 mb (shown in Figs. 91 through 94) indicate the nature of subsequent displacement of the surface wedge-front. Figure 91 indicates long term northerly flow over the wedging area, a condition favorable for rapid movement. Figure 92 indicates long term southerly flow which will discourage southward progress of the front. Figure 93 indicates that a change in flow over the wedging area is likely from northerly to southerly indicating deceleration during the latter portion of the forecast period. Figure 94 indicates a change from southerly to northerly, and that acceleration will take place during the latter portion of the forecast period. For the purpose of illustration, the basic flow patterns are examples of classical ridge and trough models; however, numerous unusual contour configurations are often observed. This fact prohibited direct use of wavelength and amplitude as parameters and made it necessary to devise a method (shown in Fig. 95) for measuring the direction of flow to the north and west of the frontal reference point. The method is based on measurements made at 850 mb. Point A is the frontal reference point. Point B is located 500 miles due north of point A and will usually lie in the cold air. Point C is obtained by following the contour over B 1000 miles upstream. The difference in latitude from A to C is a measure of the direction of flow over the wedging surface. This difference will be referred to as $\Delta\phi_N$. Point D is located 1000 miles west of Point A. Point E is taken 1000 miles upstream from D or at the intersection of the height line with the 125th meridian, whichever occurs first. The difference in latitude between E and D indicates the western extent of the flow B-C or the change in flow that exists to the west. The latitude difference E-D will be referred to as $\Delta\phi_W$. The $\Delta\phi$ values are considered positive if northerly flow is indicated and negative when southerly flow is indicated. If points B and D fall in an area of flat gradients, $\Delta\phi_N$ will then be latitude difference B-A and $\Delta\phi_W$ will be zero.

As previously mentioned, the advection factor at 700 mb northwest of the frontal reference point materially affects the subsequent displacement of the wedge-front. A simple method devised for evaluating the advection factor at 700 mb is shown in Fig. 96 and described below. From the frontal reference point, proceed 250 miles northwest to locate point B. Follow the contour over B 500 miles upstream to locate point C.

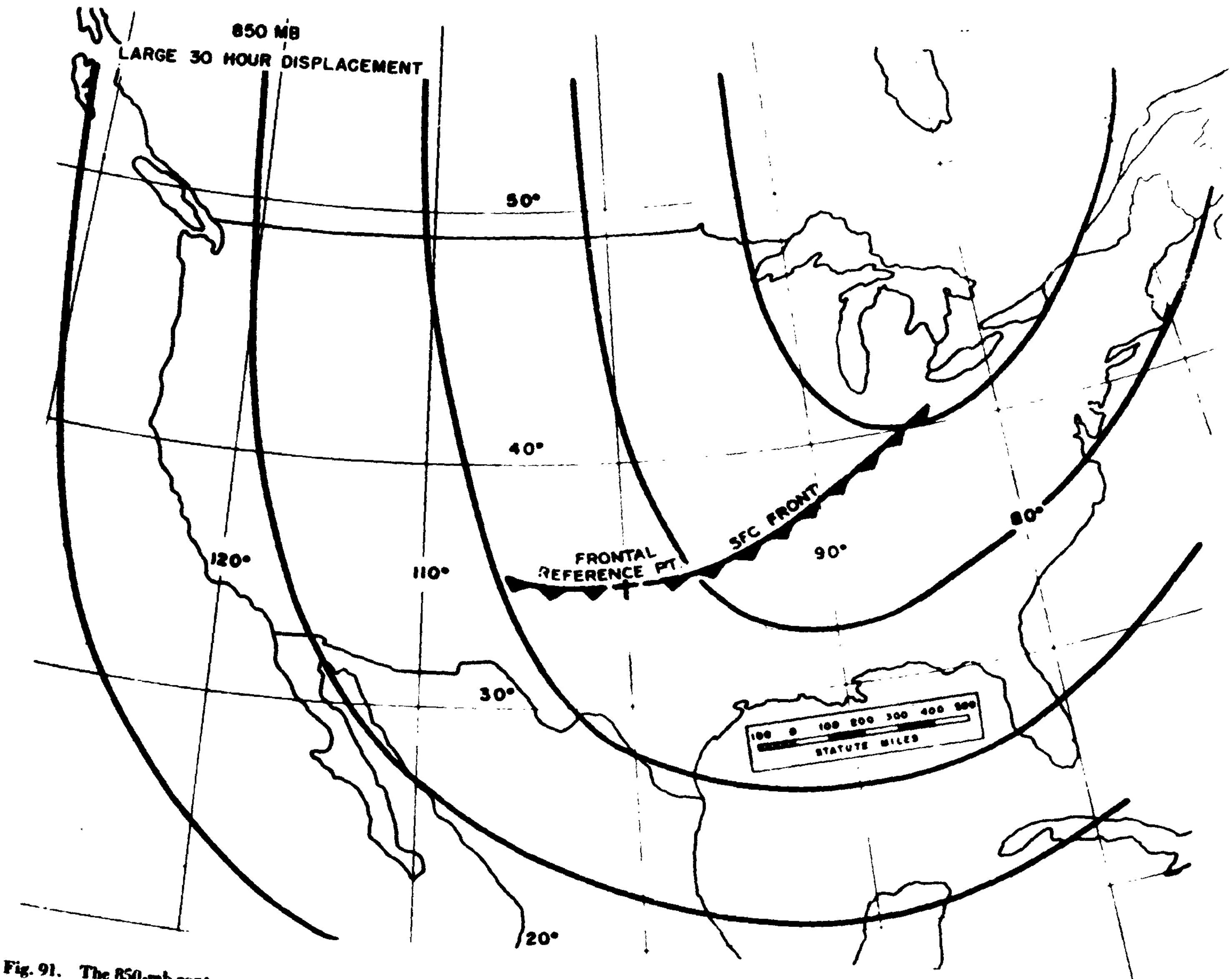

Fig. 91. The 850-mb contour pattern conducive to rapid southward movement of the Great Plains wedge front. The solid lines are 200-foot height contours.

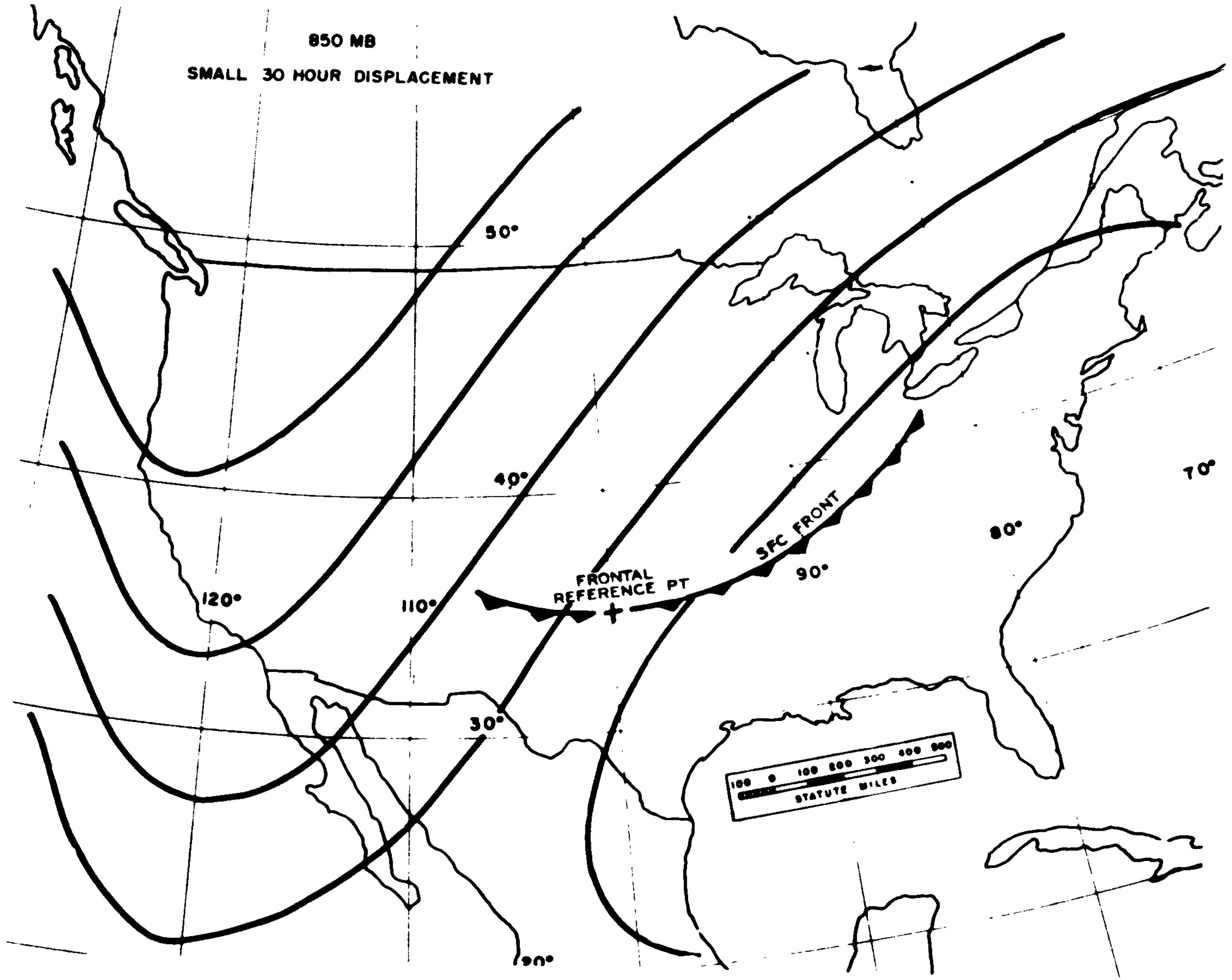

Fig. 92. The 850-mb contour pattern conducive to retarded movement of the Great Plains wedge front. The solid lines are 200-foot height contours.

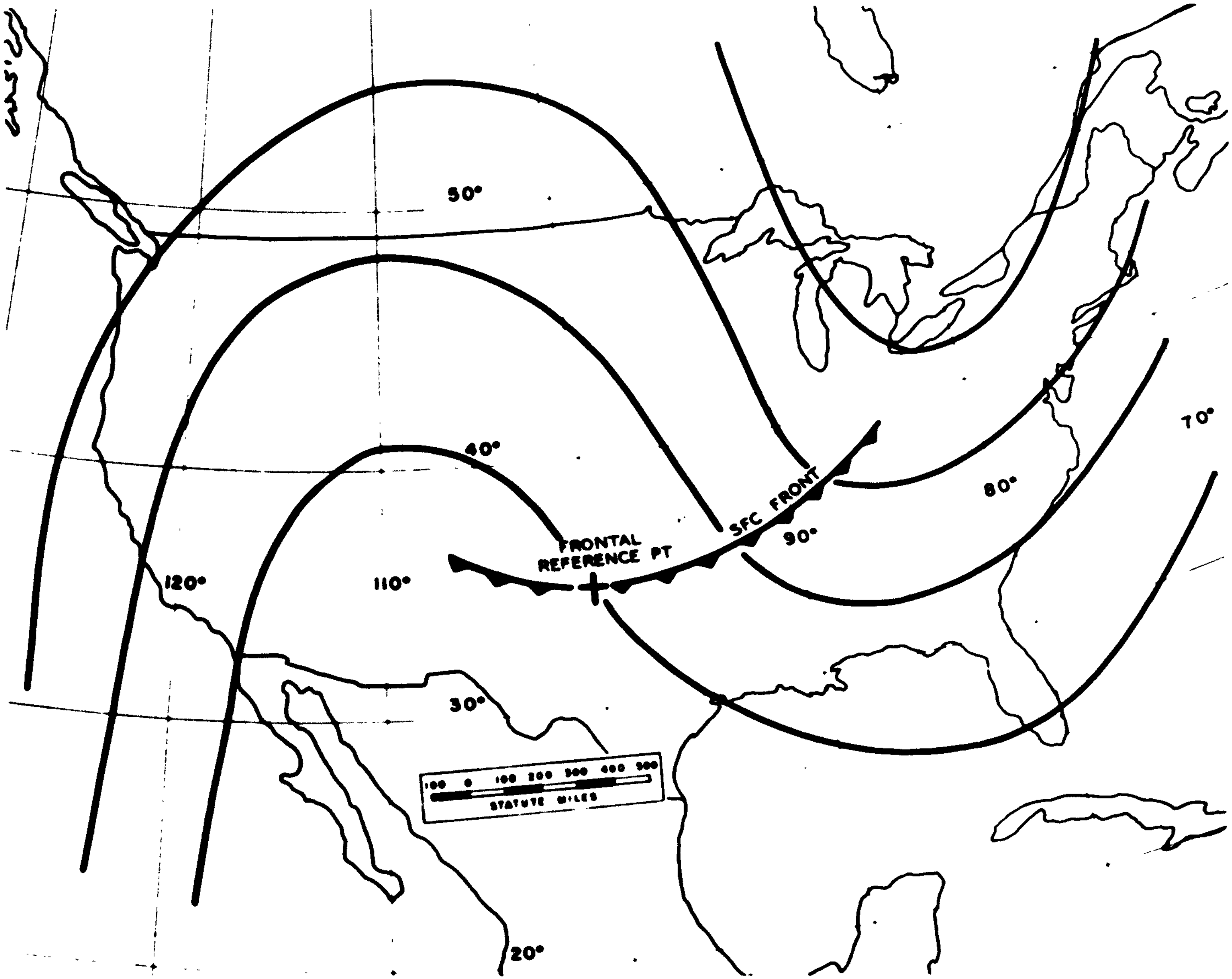

Fig. 93. The 850-mb contour pattern conducive to deceleration of the surface Great Plains wedge front during the latter portion of a 30-hour forecast period. The solid lines are 200-foot height contours.

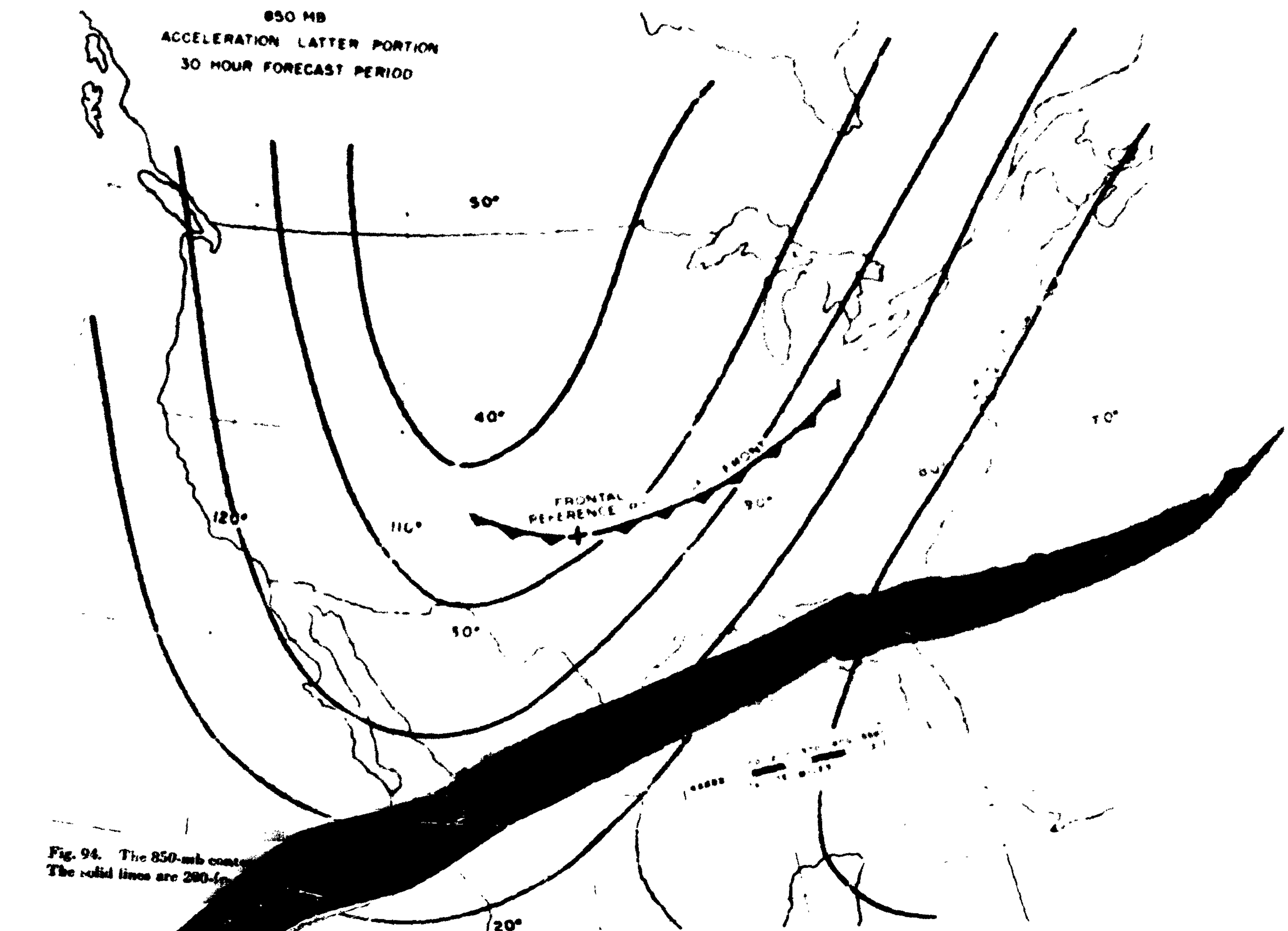

Fig. 94. The 850-mb cont[illegible] pattern conducive to acceleration of the Great Plains wedge front during the latter portion of a 30-hour forecast period. The solid lines are 200-f[illegible] height contours.

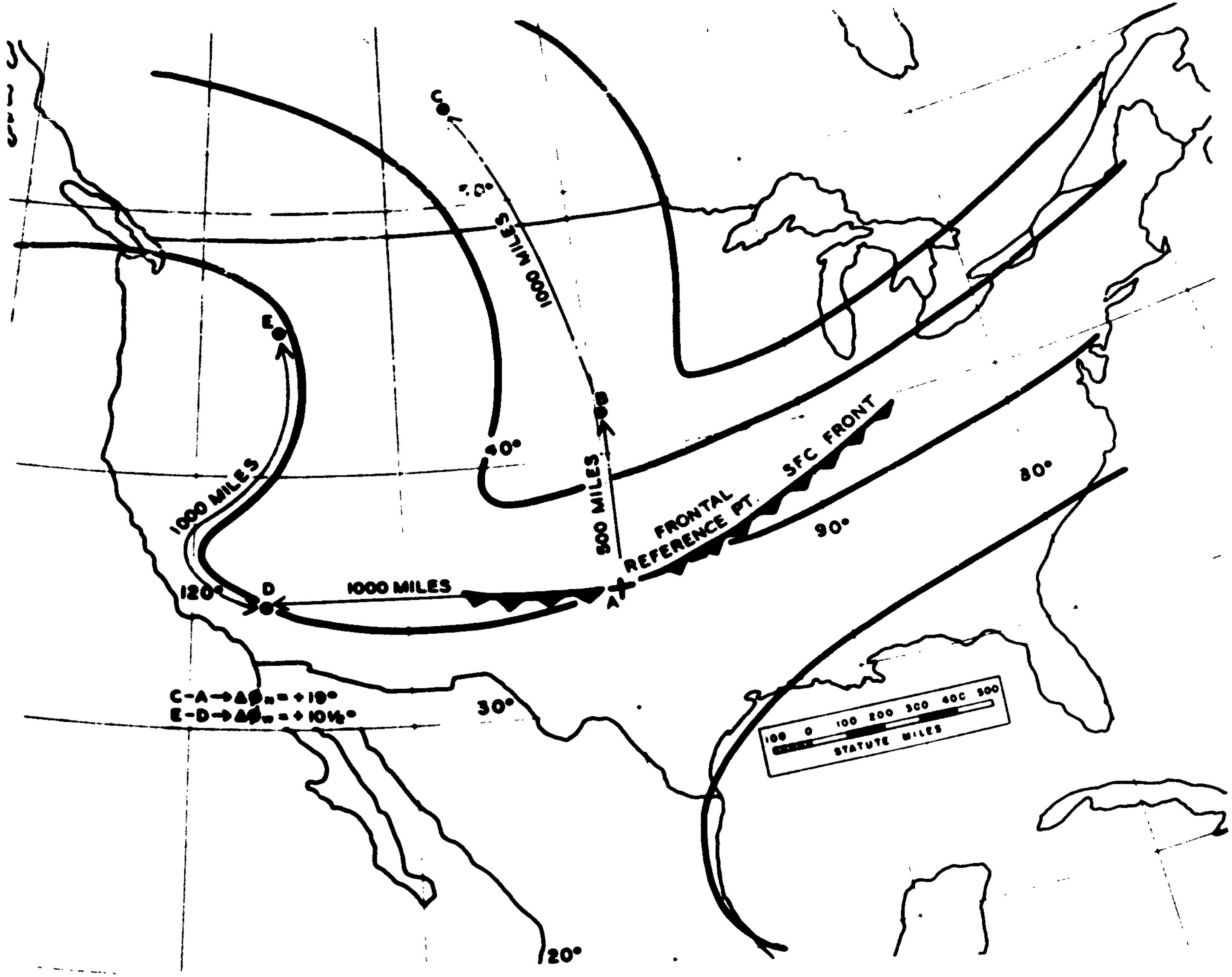

Fig. 95. Example of procedure to obtain $\Delta\phi_N$ and $\Delta\phi_W$ at 850 mb. See page 135.

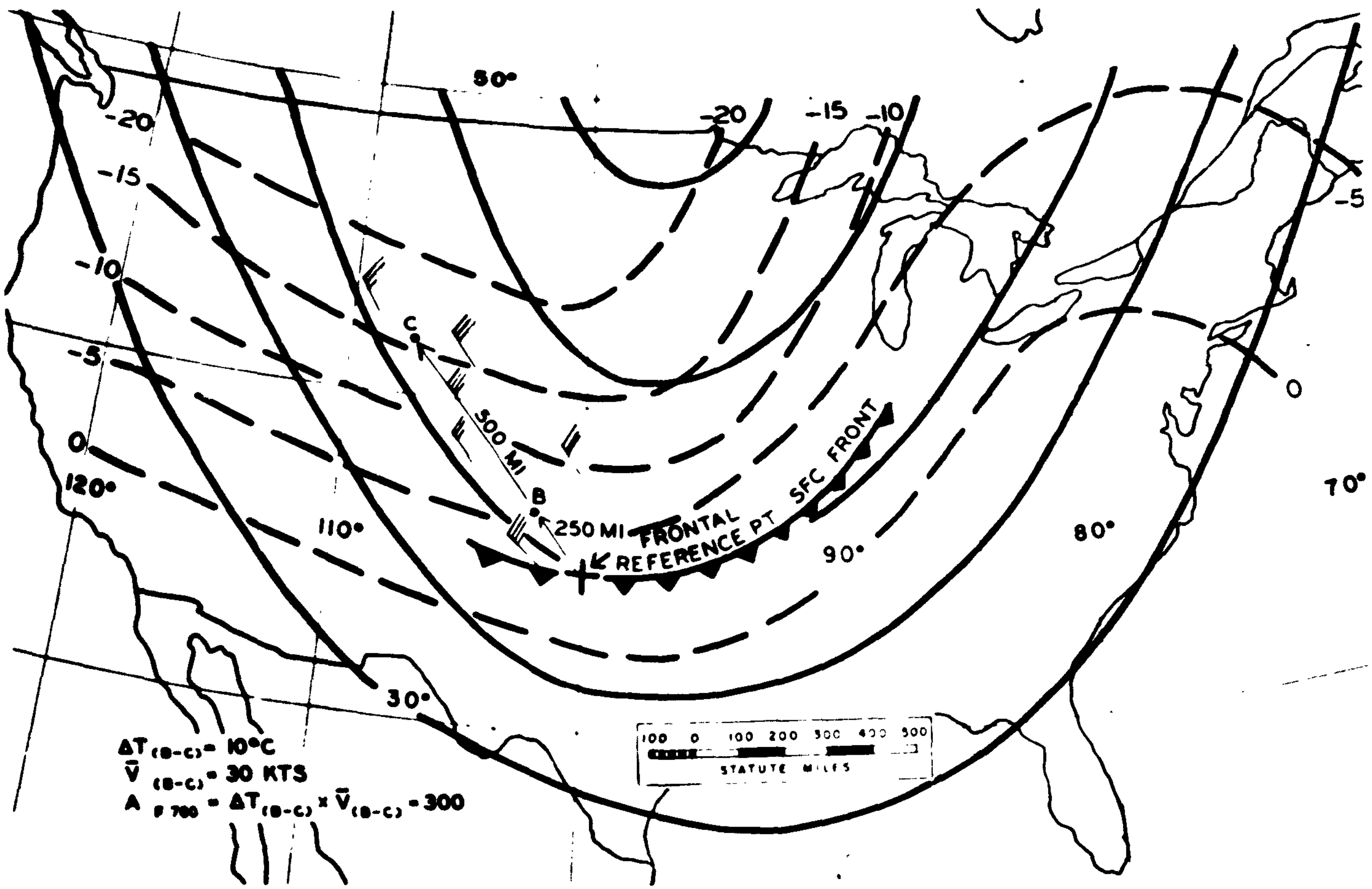

Fig. 96. Example computation of the advection factor 700 mb A_{F700} See page 135.

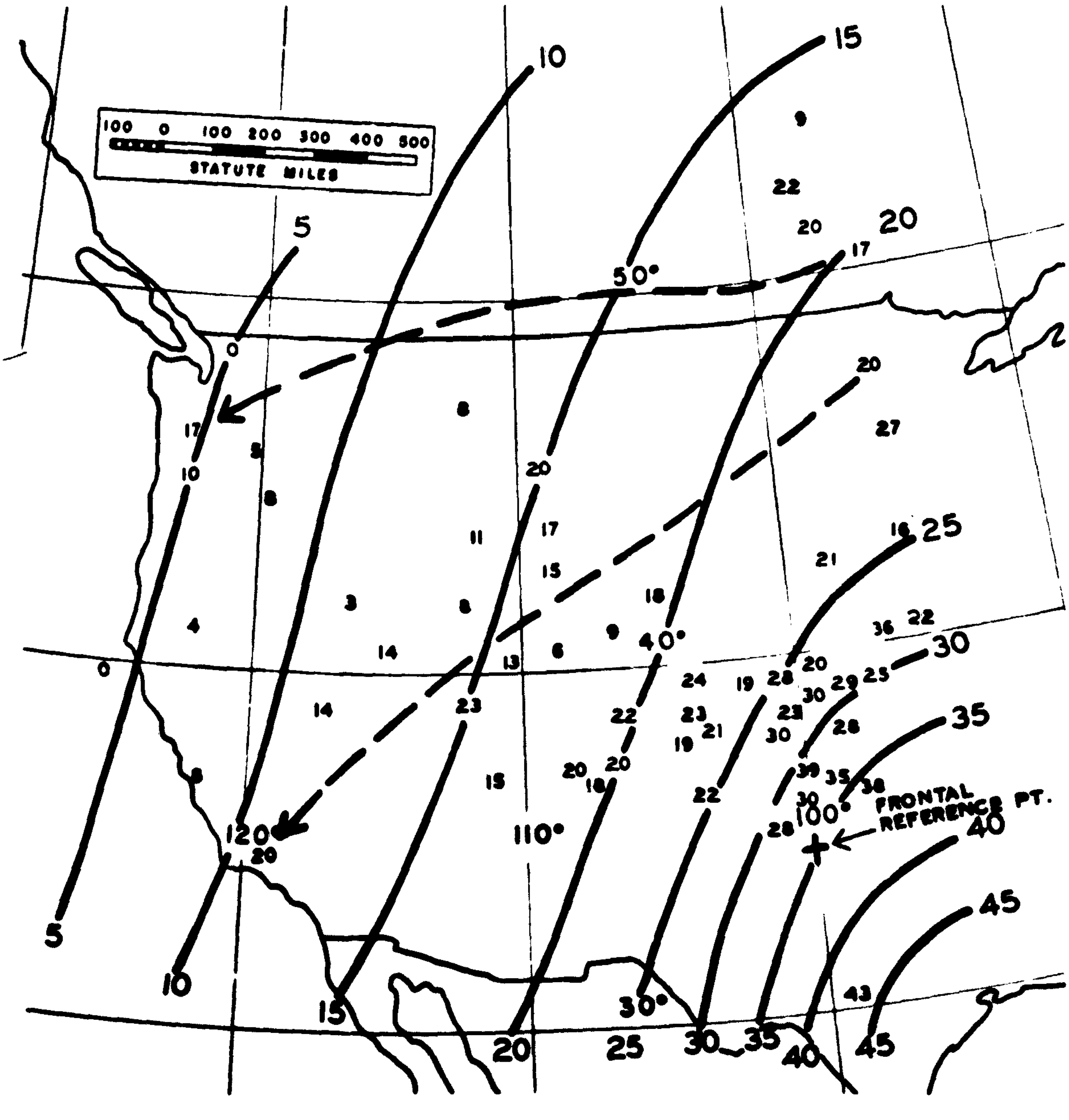

Fig. 97. An overlay graph to obtain the speed of movement of the Great Plains wedge front when a closed low exists at 850 mb west of the 95th meridian, and within 1400 miles of the frontal reference point. The heavy line should be superimposed on the 100th meridian, with the cross bar directly over the frontal reference point. Locate all low centers at 850 mb west of the 95th meridian, and within 1400 miles of the frontal reference point. The location of the 850-mb low center relative to the frontal reference point determines the forecast speed of movement (of the surface wedge front) in miles per hour for 30 hours, along a line connecting Bismarck, North Dakota, and Vera Cruz, Mexico. If more than one low center is present, obtain the forecast speed for each center using the arithmetical average for a final forecast speed.

Note the temperature difference between points B and C. Average the observed winds between the points to the nearest 5 knots. A simple multiplication $\Delta T_{(B-C)} \times \bar{V}_{(B-C)}$ is the advection factor at 700 mb, denoted $A_{F:00}$, and is considered positive when indicating cold advection and negative when indicating warm advection.

At times, the presence west of the 95th meridian of a definite closed low center at 850 mb within 1400 miles of the frontal reference point prohibits a representative computation of $\Delta \phi_N$ and $\Delta \phi_W$. Therefore, all these situations where such lows had at least one closed 200-foot contour and were verified by observed winds, were deleted from the data sample. A separate investigation of these cases indicated a strong relationship between the location of the 850-mb low center relative to the frontal reference point and subsequent frontal movement. A tissue overlay graph with a vertical line representing the 100th meridian and a cross bar for the frontal reference point was devised and utilized in this study. The overlay was placed on the 850-mb charts and all low centers west of the 95th meridian and within 1400 miles of the frontal reference point were located on the overlay. The subsequent 30-hour average speed of the front was plotted. Speed lines shown in Fig. 97, were drawn for these values, and this graph was used in forecasting. In the event that more than one low is present in the area covered by the overlay, all centers should be plotted and the final speed forecast is taken as the arithmetical average of their speeds. This method is referred to as the "closed low" method. Statistics for this method are as follows:

1. Fifty-nine cases, from January 1950 through March 1952, are included in the total data sample.
2. Thirty cases, from November 1951 through March 1952, comprise the independent data.
3. The correlation coefficient between observed and forecast speeds based on Fig. 97 is .85 for the independent data.
4. The average error for the independent data is 4.4 miles per hour.
5. The maximum error is 11 miles per hour.
6. The frequency distribution of errors in the 30-hour average speed forecast is given in Table 7.

Table 7.

Error in 30 Hr	No. Cases	Percent
0–2	10	33.3
3–5	10	33.3
6–8	6	20.0
9–11	4	13.3
12	0	0.0

When there is no closed low at 850 mb, the "open trough" forecasting method is used for the wedge-front. The parameters $\Delta \phi_N$ and $\Delta \phi_W$ are utilized in a preliminary graph shown in Fig. 98. The value given by this graph and the advection factor ($A_{F:00}$) are used in Fig. 99 to give the final speed of the cold front.

The following statistics are presented for "open trough" cases:

1. The total data sample comprising 60 cases, covers the period November 1949 through March 1952.

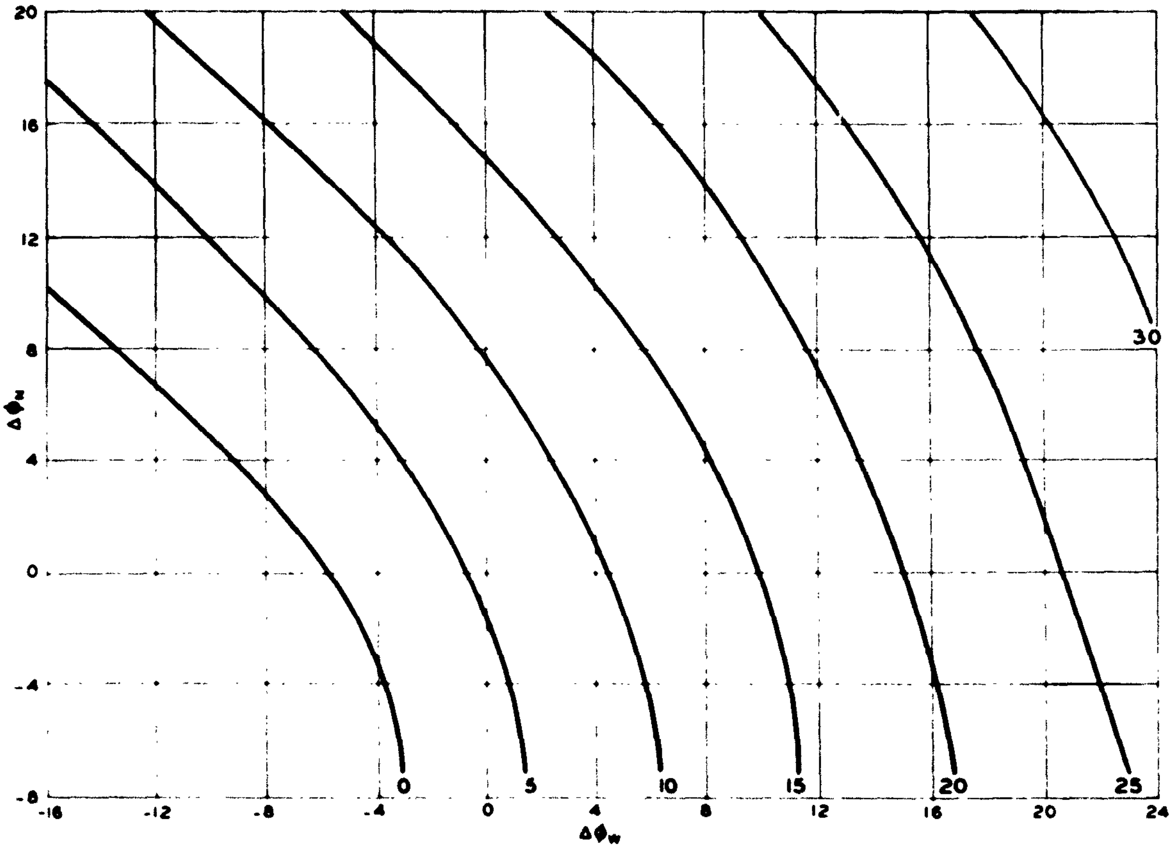

Fig. 98. Preliminary prediction I Great Plains wedge fronts (open trough category). The ordinate $\Delta\phi_N$ is plotted in 4° increments. The abscissa $\Delta\phi_W$ is plotted in 4° increments. Carry the value obtained from this figure to Fig. 99.

2. The independent data, comprising 28 cases, covers the period November 1951 through March 1952.
3. The correlation coefficient between observed and forecast movements based on Figs. 99 for the independent data is .80.
4. The average error from Fig. 99 is 2.68 miles per hour.
5. The maximum error based on Fig. 99 is 17 miles per hour.
6. The frequency distribution of errors in the 30-hour average speed forecast for 3 miles per hour increments is listed for independent data in Table 8.

Table 8.

Error mph 30 Hr	No. Cases	Percent
0–2	21	75.2
3–5	4	14.2
6–8	1	3.5
9–11	0	0.0
12	2	7.1

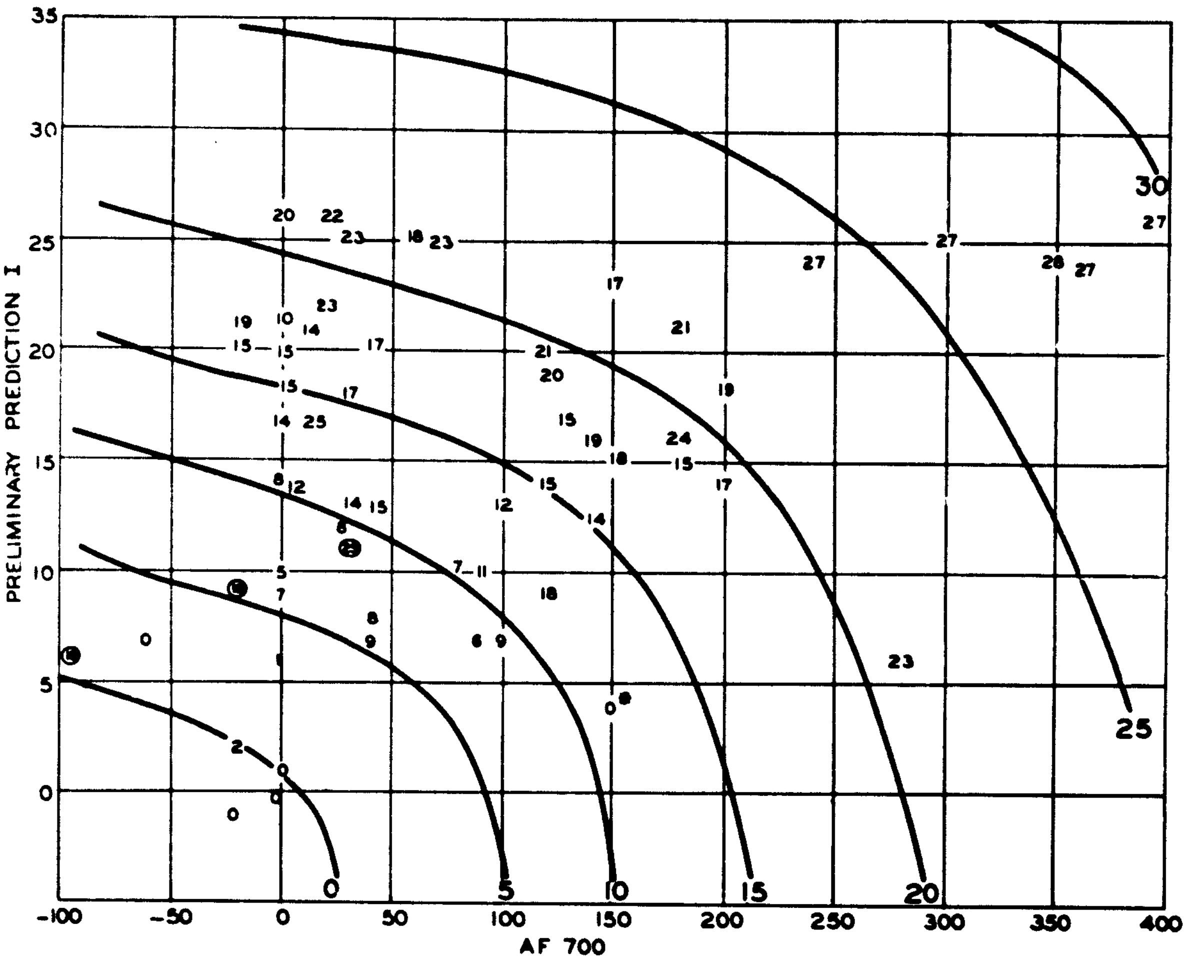

Fig. 99. The final forecast speed (open trough 850-mb category) of the Great Plains wedge front in statute miles per hour along a line connecting Bismarck, North Dakota, and Vera Cruz, Mexico. The ordinate preliminary prediction *I* is obtained from Fig. 98. The abscissa is the advection factor at 700 mb. The family of curves indicates the final speed forecast.

A casual inspection of Fig. 99 reveals four large errors. The errors occurred when a well defined ridge was just west of the frontal reference point and a trough was near the west coast of the United States. These situations fit the basic decelerating pattern shown in Fig. 93. On three of the occasions (indicated by the circled numbers in Fig. 99), the ridge remained stationary resulting in northerly flow over the wedging area for the entire 30-hour period. Two of these cases were associated with warm air advection in advance of the ridge which suggested that slow or stationary ridge movement might occur; however, other ridges of similar character moved eastward in the normal way. Since attempts to insert parameters that would reflect the movement of the ridge were unsuccessful, occasional large scale errors will result when an unusual ridge or trough displacement occurs. The fourth large error (indicated by the asterisk in Fig. 99), was the result of an unusually large deceleration pattern associated with the development of an intense low in New Mexico during the latter portion of the 30-hour forecast period. The wedge-front moved southward at the rate of 16 miles per hour for the first 18 hours, then as the New Mexico low developed and moved into north Texas it moved northward as a warm front back to its original position.

Works[illegible] Great Plains types of cold fronts are presented on page 147. The third type of cold front is associated with a high pressure wedge [illegible] over the coastal plain of the eastern United States and is often observed during the colder months of the year. These wedge formations are the result of a deformation of the southern isobars of a cold anticyclone which moves slowly eastward north of latitude 35°. The easterly component of the wind south of the high center carries the cold air directly into the Appalachian Mountain barrier which deflects the air to the south and results in a northeast-southwest orientation of the surface isobars. This synoptic development usually occurs after all frontal systems preceding the anticyclone have been forced into the Atlantic (these fronts belong to type one). However on occasion the wedge formation is directly preceded by an east-west cold front and southward progress of this wedge-front will be discussed in this section.

WORK SHEET FOR GREAT PLAINS WEDGE-FRONT *OPEN TROUGH* CATEGORY

DATE:...

TIME OF 850- AND 700-mb CHARTS:...

REQUIREMENTS:

1. The surface cold front should be approaching an east-west orientation as it crosses the 100th meridian.
2. The surface isobars north of the front should display an easterly component.

DEVELOPMENT:

1. Note the latitude where the surface front crosses the 100th meridian. Mark this point on the 850- and 700-mb charts.
2. On the 850-mb chart label the frontal reference point A and proceed 500 miles north of the frontal reference point to locate point B. Follow the contour over point B 1000 miles upstream to locate point C. The latitude difference from point A to C will be referred to as $\Delta\phi_N$. It shall be considered positive when point C is north of point A and will be considered negative when point C is located south of point A. In the event point B is located in a completely flat area $\Delta\phi_N$ will be latitude difference B to A. ....
3. From the frontal reference point proceed 1000 miles west to locate point D. Follow the contour over point D 1000 miles upstream or to the point where it crosses the 125th meridian whichever occurs first. The latitude difference E to D will be referred to as $\Delta\phi_W$. It shall be considered positive when E is located north of D and negative when E is located south of D. In the event that point D is located in a completely flat area $\Delta\phi_W$ will be zero. ....
4. With the values from two and three enter Fig. 98 for a preliminary prediction value. ....
5. At the 700-mb level proceed 250 miles from the frontal reference point to the northwest to locate point B. Follow the contour over B 500 miles upstream to locate point C. Note the temperature difference from B to C. This value will be referred to as $T_{(B-C)}$. It will be considered positive when the temperature at C is colder than at B. Average the observed winds from B to C to the nearest 5 knots. This will be referred to as $V_{(B-C)}$ .... Multiply $T_{(B-C)}$ by $V_{(B-C)}$ to obtain the advection factor at 700 mb $A_{F\,700}$ .....
6. With the values obtained from operations 4 and 5 enter Fig. 99 for a final speed prediction in statute miles per hour.
7. Move the surface wedge-front along a line connecting Bismarck, North Dakota, and Vera Cruz, Mexico, for 30 hours at the speed indicated from Fig. 99.

WORK SHEET FOR GREAT PLAINS WEDGE-FRONT *CLOSED LOW* CATEGORY

DATE:...

TIME OF 850-mb CHART:...

REQUIREMENTS:

1. The surface front should be approaching east-west as it crosses the 100th meridian.
2. The surface isobars north of the front should display an easterly component.
3. A closed low must be present at 850 mb west of the 95th meridian and within 1400 miles of the point where the surface front crosses the 100th meridian. This is the frontal reference point. The low should have at least one closed 200-foot contour with the observed winds verifying the closed circulation.

DEVELOPMENT:

1. Mark the frontal reference point on the base map. Place Fig. 97 over the base map with the cross bar over the frontal reference point, and the heavy vertical line directly over the 100th meridian. Mark the position of the geometrical center of the closed low on Fig. 97. The position of the center of the closed low indicates the average 30-hour speed in statute miles per hour.. In the event that more than one closed center exists in the area covered by Fig. 97, note the position of each center. The final speed forecast will be the arithmetical average of the speeds indicated for each low center...
2. Move the wedge-front for 30 hours along a line connecting Bismarck, North Dakota, with Vera Cruz, Mexico.

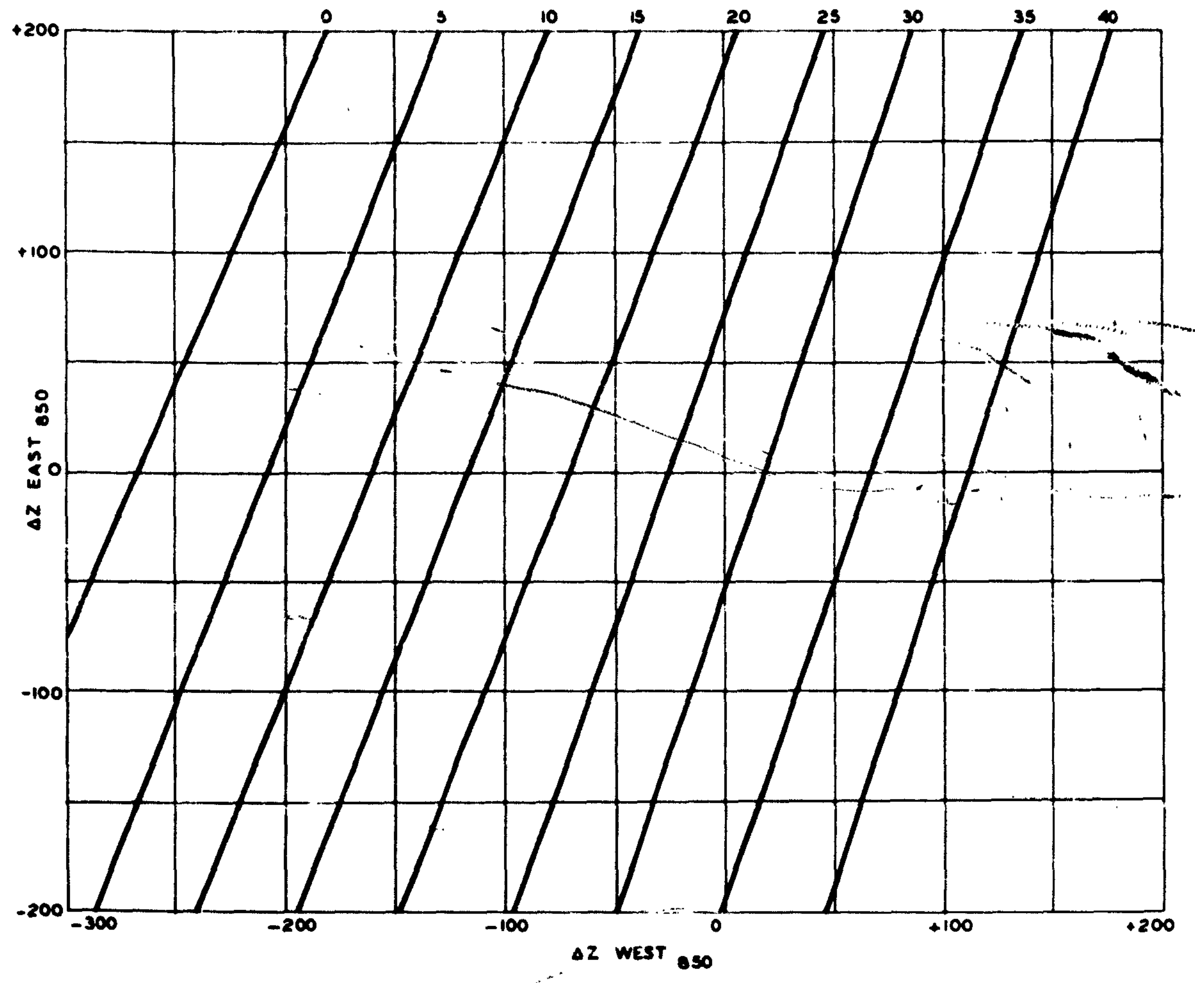

Fig. 100. Preliminary prediction I east coast wedge fronts. The ordinate ΔZ east is the height difference, corrected for latitude, at 850 mb from the frontal reference point to a point 600 miles east. The abscissa ΔZ west is the height difference, corrected for latitude, from the frontal reference point to a point 600 miles west. The ΔZ values are plotted in increments of 100 ft. Carry the value obtained from the family of curves of graph to Fig. 101.

The leading edge of the wedge is usually characterized by a nose of cold air directed towards the southwest as it advances down the coastal plain. A line connecting Caribou, Maine, and Cross City, Florida, will normally bisect the nose and be approximately the axis of the wedge formation; therefore the displacement of the wedge-front can best be measured along this line. The measurements of the parameters will be made relative to the intersection of the wedge-front with this line, which will be called the frontal reference point. The speed of displacement obtained from the graphs in this section is the average speed for a 30-hour period. Frequent short term accelerations make use of the graph speeds questionable for periods of less than 18–24 hours. Since the existence of a wedge-front in the coastal plain is rare, only a limited amount of data was available for this study. Therefore, the solutions are tentative until it will be possible to test them with independent data. The following observations are the result of a subjective study of upper air charts relative to the subsequent 30-hour displacement of the surface wedge-front.

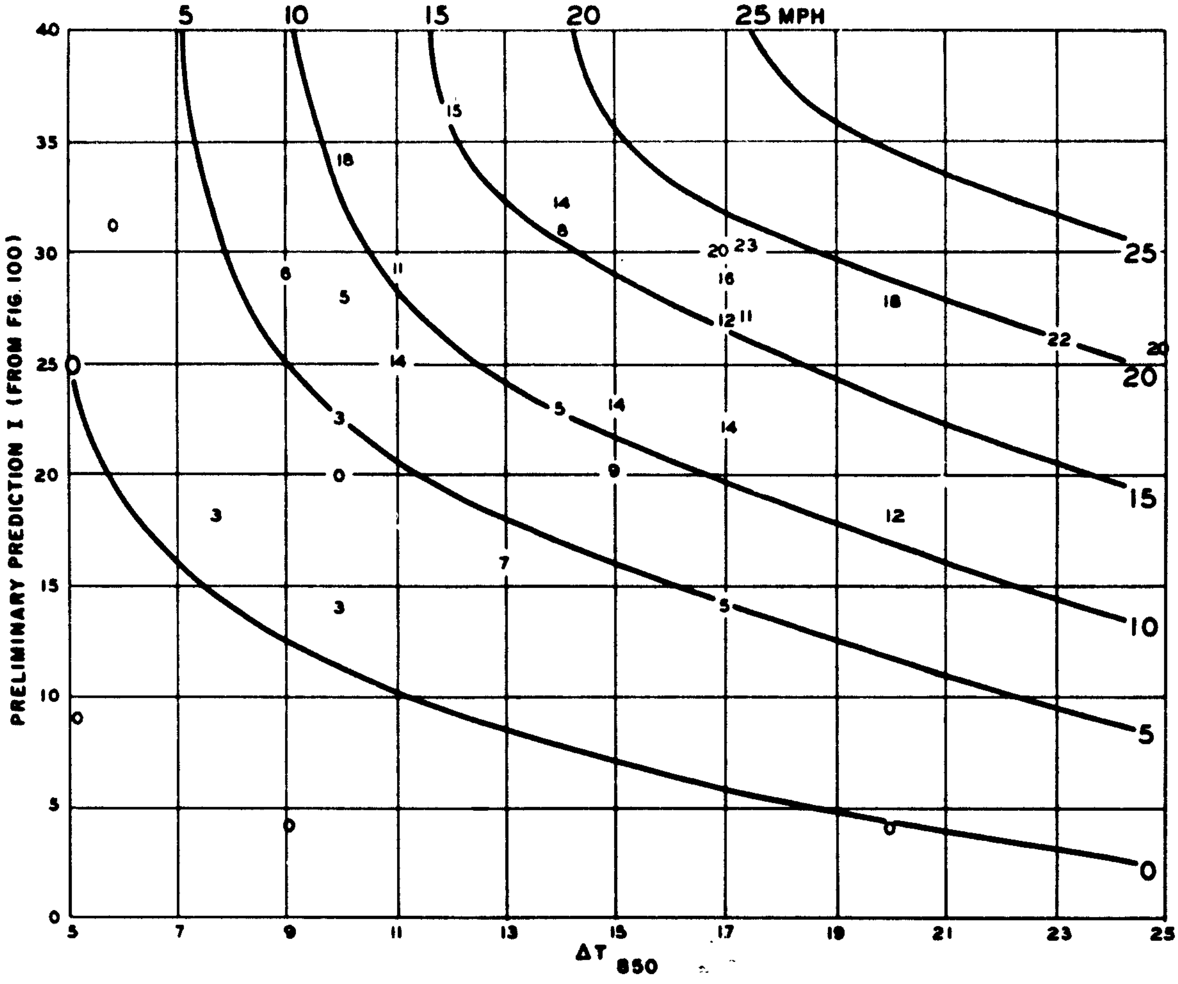

Fig. 101. The final forecast speed of east coast wedge fronts in statute miles per hour, for 30 hours, along a line connecting Caribou, Maine, and Cross City, Florida. The ordinate is the preliminary prediction from Fig. 100. The abscissa ΔT_{850} is the temperature difference in degrees centigrade measured 600 miles from the frontal reference point toward the northeast, along the line connecting Caribou, Maine, and Cross City, Florida.

1. A steep temperature gradient at 850 mb to the northeast of the frontal reference point is conducive to large southward displacement of the surface wedge-front.
2. A weak temperature gradient at 850 mb to the northeast of the leading edge of the wedge is conducive to small southward displacement.
3. Northerly flow at 850 mb over the leading edge of the wedge is conducive to large southward displacement of the surface wedge-front.
4. Southerly flow at 850 mb over the leading edge of the wedge is conducive to small southward displacement of the surface wedge-front.

The transfer of these subjective observations into objective parameters was accomplished in the following manner:

1. The temperature gradient at 850 mb was measured from the frontal reference point 600 miles toward the northeast along a line connecting Caribou, Maine, and Cross City, Florida. The value obtained from this operation will be referred to as ΔT_{850}.
2. The height difference 600 miles west and 600 miles east of the frontal reference point at 850 mb was measured and corrected for the latitude. The values obtained from this operation will be referred to as ΔZ west $_{850}$ and ΔZ east $_{850}$ and will be considered positive when the height increases as we move away from the frontal reference point and negative when there is a decrease in height away from the frontal reference point.

The ΔZ values are utilized in a preliminary forecasting graph shown in Fig. 100. The result obtained from Fig. 100 is plotted as the ordinate and ΔT_{850} as the abscissa in Fig. 101. This graph gives the forecast speed (in miles per hour) of the frontal reference point for 30 hours along the line connecting Caribou, Maine, and Cross City, Florida. The following statistics are given for these cases:

1. Thirty wedge-front situations comprise the total data sample for the period November 1949 through March 1951.
2. There were insufficient data for a representative independent check.
3. The correlation coefficient between observed speeds and forecast speeds based on Fig. 101 is .88 for the dependent data.
4. The average error is 2.2 miles per hour.
5. The maximum error is 8 miles per hour.
6. The frequency distribution of errors in the 30-hour average speed for 3 miles per hour increments is given below for the dependent data.

Table 9.

Error mph 30 Hrs	No. Cases	Percent
0–2	18	60
3–5	10	33.3
6–8	2	6.7

Catalog of cases for all categories of surface fronts appears in Appendix VII. The dependent data samples for Category I cold fronts and Great Plains wedge-fronts have been omitted due to the large volume of the sample. The entire data sample for the east coast wedge-front is included.

On the following page is presented a sample worksheet.

WORK SHEET FOR THE EAST COAST WEDGE-FRONT

DATE: ....

TIME 850-mb CHART: ....

REQUIREMENTS:

1. Front must be approaching east-west as it crosses a line connecting Caribou, Maine, with Cross City, Florida.
2. Surface isobars north of front should display an easterly component.

DEVELOPMENT:

1. Construct a line on the 850-mb chart connecting Caribou, Maine, and Cross City, Florida.
2. Note the latitude of the point where the surface front crosses the Caribou-Cross City line. This is the frontal reference point.
3. Measure the difference in height between the frontal reference point and a point 600 statute miles to the west and correct this value for latitude. The corrected value is ΔZ west .... (If the height increases to the west, the value is positive. If the height decreases to the west, the value is negative.)
4. Measure the difference in height between the frontal reference point and a point 600 miles to the east. Correct this value for latitude. The corrected value is ΔZ east .... (If the height increases to the east, the value is positive. If the height decreases to the east, the value is negative.)
5. Measure the difference in temperature in degrees Centigrade from the frontal reference point to a point 600 miles to the northeast along the line connecting Caribou and Cross City. This value is ΔT_{850} ....
6. With the values from operations 3 and 4 enter Fig. 100 for a preliminary prediction value.
7. With the value from Fig. 100 and the ΔT_{850} obtained from operation 5 enter Fig. 101 for a final speed forecast in statute miles per hour.
8. Move the frontal reference point with the speed indicated from Fig. 101 for 30 hours along the line connecting Caribou and Cross City.

APPENDIX I. Table 2.

J - Center Jump
N - Negative Case
S - Cold Tongue
C - Special Category Primary
F - Failure
PF - Partial Failure

850 MB CHART														FROM 500 MB CHART				FROM SURFACE CHART									
				INJECTION			ORIENTATION		AMPLITUDE									PRIMARY STORM				NEW STORM INTENSITY					
Case No.	Date and Time of Injection	Date and Time of Cyclogenesis	Temperature at Time of C/G	Latitude (Inj/C/G)	Average Wind Speed	Thermal Range	Contours	Isotherms	Contours	Isotherms	Distance C_i to Primary (Miles)	ΔT 1000 Miles NW	Geostrophic Wind	ΔT 1000 Miles (C°) East & West	Sharpness of Trough (Feet)	Distance to Trough (Miles)	Speed of Trough Past 12 Hrs (mph)	Course	Speed	Did 18 Hour Position Fall in CJ Circle	Central Pressure	P	P + 12 Hrs	P + 24 Hrs	P + 36 Hrs	Initial Course	12 Hour Speed
NOVEMBER 1948																											
101[N]	4/1000	None	—	36/	50	15	35	20	18	9	400	15	35	—	—	—	—	25	28	No	989	None		—	—	None	—
102[N]	5/1000	None	—	30/	35	17	35	25	27	18	1100	23	46	—	—	—	—	350	20	No	988	None		—	—	—	—
103	7/1000	8/0730	7	39/38	25	18	43	40	U	4	300	15	NA	5	525	925	--	145	15	NA	1008	7	8	10	13	60	18
104[PF]	9/1000	10/0730	10	30/38	35	20	32	28	17	18	1100	18	37	—	—	1000	—	31	30	No	1004	6	Filled		—	U	U
105	10/1000	11/0130	14	32/36	30	15	38	45	23	22	1450	23	22	15	1095	1050	40	16	50	No	980	6	Filled		—	U	U
106[S]	12/2200	13/1330	2	40/43	35	17	NA	NA	NA	NA	600	21	40	10	1010	800	--	62	40	Yes	1006	21	26	off map	—	62	52
			12	41						11				8	435	800						19	29	18	15	25	35
107[S]	15/2200	16/1930	12	44/34	35	18	50	40	8		400	20	30	1	418	550	—	42	30	NA	1001	5	5	Filled		85	60
108[C]	18/2200	20/1330	5	30/42	50	23	25	13	25	18	650	17	30	9	1070	1400	28	Stat.	—	NA	994	10	13	14	off map	61	40
109	21/1000	22/1330	10	35/30	22	21	55	48	5	6	1050	25	NA	8	765	1350	0	Stat.	—	NA	1014	4	6	Filled		62	15
																									7		
110	21/2200	22/1930	9	32/37	25	17	43	40	10	10	1100	18	20	12	890	1300	5	62	20	No	1015	6	7	6	Jump	55	30
111[J]	22/1000	23/1330	12	28/33	20	15	55	35	10	13	700	22	NA	—	—	—	—	77	10	Yes	1012	7	6	6	6?	70	12
112[J]	23/2200	25/0130	8	28/37	25	11	62	50	6	9	1300	23	20	—	—	—	—	Stat.	—	Yes	1006	8	16	17	off map	55	45
113	25/1000	26/0730	16	37/30	30	14	45	75	20	7	350	20	30	6	550	875	—	39	50	NA	1081	3	5	6	Fill	70	42
																								22	17		
114	26/2200	28/0130	13	32/33	25	25	50	65	10	5	500	22	15	9	1170	1100	18	144	30	NA	1002	13	16	Jump	—	81	26
115[J]	27/2200	28/1430	10	29/35	30	20	45	50	20	10	550	25	24	—	—	—	—	85	22	Yes	1003	9	22	17	13	30	15
116[N]	29/2200	None	—	32/	40	25	NA	NA	NA	NA	1300	NA	NA	—	—	—	—	65	25	No	1006	None		—	—	—	—
DECEMBER 1948																											
117	1/2200	2/1330	14	31/28	35	12	40	35	12	7	250	20	NA	4	585	1300	20	107	28	Yes	1010	3	6	11	10	35	30
118[J]	3/2200	4/0730	10	34/37	25	12	30	20	10	5	500	15	33	—	—	—	—	Stat.	—	Yes	1008	12	10	13	19?	83	12
119[N]	5/1000	—	—	35/	50	18	NA	NA	NA	NA	1100	NA	NA	--	—	—	—	None	—	—	978	None		—	—	None	—
120	7/1000	8/1330	15	31/29	25	17	62	55	8	10	2600	27	NA	2	300	950	32	U	U	No	980	5	5	8	8	62	24
121[J]	11/2200	13/0130	−10	38/45	25	20	55	45	22	4	1000	15	35	—	—	—	—	90	32	Yes	998	10	13	18	off map	63	36
122	14/2200	15/1930	5	40/37	18	18	60	40	15	7	250	21	20	12	1210	2200	20	56	10	NA	1006	7	6	5	9	Stationary	—
123	16/1000	17/0730	[illegible]	36/35	24	23	92	55	U	10	1200	26	20	2	670	2400	0	90	30	No	996	4	Filled		—	140	24
124[PF]	17/1000	18/0130	−10	35/49	25	13	45	60	U	7	1400	20	25	—	—	—	—	71	26	No	996	15	13	off map	—	57	26
125	16/2200	18/0730	12	40/31	40	15	80	72	0	5	900	30	NA	4	125	0	?Fades	52	34	NA	997	4	4	Jump	—	90	50
126[J]	18/1000	19/0130	8	35/33	35	27	50	45	11	8	900	28	15	—	—	—	—	90	40	Yes	1012	6	23	19	14	32	30
			CG	38/																		10	7	Filled		102	20
127[J]	20/1000	21/0130	10/−8	34/45	30	17	90	0	0	8	850	17	27	--	—	—	—	103	20	Yes	983	16	8	7	Fill	80	28
128	21/2200	22/1930	11	34/32	25	13	65	75	3	3	1450	20	NA	4	—	2500?	—	101	50	No	1004	3	Filled		—	90	U
129	22/1000	23/0730	−3	38/42	25	20	90	80	0	1	1350	20	20	—	—	—	—	U	U	U	1007	7	11	off map		63	30
130	23/2200	25/0130	14	32/32	25	22	100	90	Neg.	0	350	30	NA	7	960	1700	44	111	40	NA	1007	8	Jump		—	106	36
131[J]	24/1000	25/0730	7	35/32	22	25	U	50?	U	8	950	30	NA	4	80	1700	26	102	24	Yes	1012	6	15	18	15	75	13
132[J]	28/1000	29/1330	−5	34/44	50	17	50	40	13	12	400	27	28	—	—	—	—	73	32	Yes	997	16	13	Absorbed		73	52
133[J]	28/2200	30/0130	7	32/36	40	28	45	25	18	8	800	23	56	—	—	—	—	77	25	Yes	1000	10	17	17	24	65	40
JANUARY 1949																											
134[N]	2/2200	—	—	34/	30	27	NA	NA	NA	NA	150	—	—	—	—	—	—	—	—	—	994	—	—	—	—	—	—
135[N]	4/1000	5/0730	10	32/35	25	25	NA	NA	NA	NA	650	NA	NA	14	1520	1075	6	22	38	NA	999	10	Filled		—	U	U
136	5/2200	—	—	31/	25	18	NA	NA	NA	NA	1350	NA	NA	—	—	—	—	25	50	—	986	—	—	—	—	NA	NA
137	8/2200	9/1930	7	40/38	20	12	53	15	12	10	650	17	28	10	1120	2500	0	60	40	NA	1008	3	U	U	U	U	U
138	10/2200	12/0130	10	41/37	15	22	U	95	U	0	None	25	NA	21	2200	2100	0	None	—	—	—	7	5	Fill		115	50
139[N]	15/2200	—	—	41/	35	30	45	10	17	11	700	28	35	—	—	—	—	50	50	NA	998	NA	—	—	—	—	—
140	17/1000	18/0730	5	27/32	25	23	20	26	U	12	2000	24	NA	16	1520	1000	20	118	42	NA	1006	10	20	37	39	28	52
141[N]	18/2200	None	—	32/	30	40	—	—	—	—	1100	—	—	—	—	—	—	47	60	—	982	—	—	—	—	—	—
		21/0730	−12	41																						80	52
142	20/1000	21/0730	16	47/27	25	25	16	38	22	5	300	32	22	2	745	1600	0	123	22	NA	1012	5	3	Filled		40	40

APPENDIX I. Table 2 (Concluded)

850 MB CHART														FROM 500 MB CHART				FROM SURFACE CHART									
				INJECTION			ORIENTATION		AMPLITUDE									PRIMARY STORM				NEW STORM INTENSITY					
Case No.	Date and Time of Injection	Date and Time of Cyclogenesis	Temperature at Time of C/G	Latitude (Inj/C/G)	Average Wind Speed	Thermal Range	Contours	Isotherms	Contours	Isotherms	Distance C/G to Primary (Miles)	ΔT 1000 Miles NW	Geostrophic Wind	ΔT 1000 Miles (C°) East & West	Sharpness of Trough (Feet)	Distance to Trough (Miles)	Speed of Trough Past 12 Hrs (mph)	Course	Speed	Did 18 Hour Position Fall in CJ Circle	Central Pressure	P	P + 12 Hrs	P + 24 Hrs	P + 36 Hrs	Initial Course	12 Hour Speed
JANUARY 1949 (Cont.)																											
143	21/1000	21/1930	2	31/37	20	8	40	59	17	7	450	28	40	5	425	1500	Fades away	74	50	No	1014	4	9	Filled		25	38
																								9	8	45	
144	22/2200	23/1930	U	29/43	30?	18	18	30	15+	15	900	32	24	13	1230	1500	—	U	U	No	1000	12	14	Jump		—	32
145[J]	23/2200	24/1330	−2	40/43	25	35	55	15	16	9	550	32	25	—	—	—	—	68	40	Yes	1015	9	8	—	—	75	82
																							8	9	—		
146	24/2200	26/0130	10	41/38	18	23	81	35	0	9	None	31	NA	10	1120	1750	24	None	—	—	—	6	11	Jump		47	33
147[J]	25/2200	26/1930	8	37/37	10	12	50	17	U	8	750	28	NA	—	—	—	—	63	30	Yes	1022	8	9	off map		83	70
148[NP]	27/1000	—	—	30/	40	18	—	—	—	—	550	—		—	—	—	—	48	38	—	1002	—	—	—	—	—	—
149[N]	28/1000	—	—	41/	30	23	—	—	—	—	800	—		—	—	—	—	65	50	No	992	—	—	—	—	—	—
150	28/2200	29/1930	13	32/32	25	35	63	45	NA	NA	1900	NA	NA	9	920	2100	10	U	U	NA	992	5	no data			NA	—
151	29/1000	30/1330	8	31/28	23	23	60	60	U	20	None	32	NA	7	9000	1300	0	None		—	—	11	7	8	15	new storm 25	20
152	30/1000	31/0730	−1	24/35	25	20	42	42	U	15	800	32	25	9	850	1500	30	25	42	NA	1008	8	15	11	15	18	50
FEBRUARY 1949																											
153	1/1000	2/0730	10	36/30	12	17	90	40	0	9	None	23	NA	—	—	—	—	None		—	—	4	Filled		—	—	16
154	3/1000	4/0130	7	33/34	23	15	37	16	14	15	300	27	30	9	300	1800	0	60	61	NA	1010	5	10	8	8	39	40
155	4/1000	5/1330	12	30/32	18	17	70	68	8	10	1450	24	28	7	400	1800	0	82	44	NA	1006	3	4	3	Fill	70	15
156[PP]	5/2200	6/1930	12	37/30	22	15	60	60	9	5	900	25	20	—	—	—	—	79	15	Yes	1005	3	Filled		—	65	50
157	6/1000	7/0730	−3	36/38	30	22	34	52	12	5	800	25	40	5	770	1400	24	68	24	No	999	8	15	24	off map	40	48
158[N]	7/2200	Neg.	—	41/	—	—	—	—	—	—	500	—	—	—	—	—	—	58	40	NA	999	—	—	—	—	—	—
159	8/2200	9/1930	12	32/31	20	13	64	64	7	12	1650	27	35	7	820	1100	0	64	50	No	994	4	8	16	24	68	55
160[NP]	10/1000	Neg.	—	32/	—	—	—	—	—	—	850	—	—	—	—	—	—	48	40	NA	1004	—	—	—	—	—	—
161	11/2200	13/0130	3	45/40	28	37	52	54	15	7	550	38	46	13	1475	1700	14	60	50	NA	1001	16	9	Absorbed		55	68
162	13/1000	14/1330	10	40/36	20	35	74	32	U	13	800	35	40	16	1530	1400	10	140	30	NA	1010	5	11	19	12	36	50
163	14/2200	16/0130	14	35/30	35	22	57	37	14	13	900	28	54	10	935	1150	36	33	55	NA	1000	4	10	15	25	48	60
164	16/1000	17/1330	12	32/24	18	17	52	72	9	12	1000	30	NA	8	250	1500	Faded	60	60	No	1014	3	3	Fill		Stat.	10
165	18/1000	19/1330	9	38/36	25	27	40	50	10	10	1500	30	40	0	150	625	0	61	58	No	994	5	8	Jump		50	37
166[PPJ]	19/2200	20/0730	5	43/40	15	30	38	64	11	6	U	30	25	—	—	—	—	50	38	Yes	1016	12	16	9?	off map	62	40
167	20/1000	21/1330	5	42/39	15	13	—	25	—	5	1400	25	13	4	240	1700	20	U	U	No	1014	3	6	10	11	41	30
168[SJ]	24/2200	25/1930	3	38/40	35	15	40	55	U	5	600	25	50	—	—	—	—	86	30	Yes	1003	9	12	19	19	55	48
																								7	15		
169	25/2200	27/0130	11	32/29	20	11	55	65	U	4	1200	23	NA	2	350	1900	0	67	25	No	1015	3	3	Jump		72	19
	26/2200	27/1330	8	32/38	18	18	U	60	U	5	950	16	15	9	315	900	38	90	25	No	1011	6	14	Fill		53	29
170[J]	—	47/1930	10	31	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	7	15	18	25	20	40
MARCH 1949																											
171	4/2200	5/1930	−4	51/42	22	15	66	65	U	3	U	20	30	1	375	100	Neg.	U	U	U	U	8	11	14	off map	70	38
172	5/2200	6/1930	10	41/36	28	17	64	72	U	U	700	32	27	−2	75	450	0	45	50	NA	1003	11	14	Absorbed		61	58
173	6/1000	7/0730	11	38/35	30	27	57	50	U	'	1650	33	32	3	445	875	10	40	60	No	996	13	22	22	22	92	38
174[J]	8/1000	9/0130	10	34/35	30	15	60	22	11	14	200	15	20	—	—	—	—	98	25	Yes	1005	11	13	22	—	70	10
175[J]	9/1000	10/0730	10	31/36	40	22	42	40	10	10	600	21	25	—	—	—	—	66	28	Yes	1002	16	15	14	18	78	32
																							6	11	27		
176	13/2200	14/1330	12	36/29	12	23	98	50	Neg.	3	400	27	NA	4	175	1100	30	U	U	No	1018	5	Jump		—	75	36
177[J]	14/1000	15/0130	8	29/32	13	13	52	65	6	3	800	25	18	—	—	—	—	75	26	Yes	1014	6	11	27	26	41	50
178[J]	17/2200	18/1330	−3	34/40	25	22	73	64	5	3	700	25	23	—	—	—	—	84	32	Yes	1004	16	20	16	—	46	42
179[N]	21/1000	Neg.	—	29/	—	—	—	—	—	—	350	—	—	—	—	—	—	36	50	No	999	—	None	—	—	—	—
180[N]	23/2200	Neg.	—	32/	—	—	—	—	—	—	550	—	—	—	—	—	—	40	45	No	994	—	—	—	—	—	—
181[N]	26/1000	27/0730	13	31/32	35	12	30	30	17	19	850	20	30	11	—	1000	8	65	20	No	998	4	Filled		—	—	—
182[J]	30/1000	31/1330	7	32/40	30	15	30	15	U	14	550	16	23	—	—	—	—	81	24	Yes	997	13	10	5	6	U	U

APPENDIX I. Table 3.

J - Center Jump
N - Negative Case
S - Cold Tongue
C - Special Category Primary
F - Failure
PF - Partial Failure

850 MB CHART														FROM 500 MB CHART				FROM SURFACE CHART									
				INJECTION			ORIENTATION		AMPLITUDE									PRIMARY STORM				NEW STORM INTENSITY					
Case No.	Date and Time of Injection	Date and Time of Cyclogenesis	Temperature at Time of C/G	Latitude (Inj/C/G)	Average Wind Speed	Thermal Range	Contours	Isotherms	Contours	Isotherms	Distance C_J to Primary (Miles)	ΔT 1000 Miles NW	Geostrophic Wind	ΔT 1000 Miles (C) East & West	Sharpness of Trough (Feet)	Distance to Trough (Miles)	Speed of Trough Past 12 Hrs (mph)	Course	Speed	Did 18 Hour Position Fall in CJ Circle	Central Pressure	P	P + 12 Hrs	P + 24 Hrs	P + 36 Hrs	Initial Course	12 Hour Speed
NOVEMBER 1949																											
201	2/1000	3/0730	5	39/37	30	18	73	40	13	7	950	14	22	5	815	1000	-	170	20	NA	1005	7	8	14	17	65	15
202F	9/1000	10/0730	7	33/30	15	12	U	76	U	3	None	13	NA	2	170	2000	0	None		—	—	3	3	5	4	72	20
203	12/2200	14/0130	15	23/28	20	8	19	10	U	20	1700	11	NA	1	180	1000	0	42	20	NA	1003	5	7	7	5	49	18
204	15/1000	16/0730	6	39/34	42	12	53	29	U	12	1000	18	15	4	460	500	--	U	U	No	999	3	5	5	17	60	31
205	20/2200	21/0130	7	40/37	35	17	83	80	U	U	1950	27	25	5	960	820	-	45	30	No	996	8	20	24	—	61	27
206	28/1000	29/1330	−1	39/41	30	15	38	73	U	3	1350	19	23	0	400	950	-	43	18	No	978	9	13	Absorbed		44	34
207	29/1000	30/1930	8	35/37	25	20	34	75	15	2	1700	18	25		—			U	U	NA	984	10	U	U	U	U	U
DECEMBER 1949																											
208J	1/1000	2/1330	−6	39/39	28	18	80	70	1	1	500	17	23				—	87	30	Yes	1012	10	13	10	11	75	30
209	4/1000	5/1330	−3	35/42	25	19	67	30	15	6	1700	17	22	15	1240	1000	36	90	35	No	1000	11	21	23	—	27	35
210PF	11/2200	13/1330	10	37/37	35	20	51	6	20	18	1150	32	56			-	—	43	42	No	980	4	Filled		—	U	U
211	12/2200	14/0730	15	33/25	17	12	54	54	15	20	None	30	NA	4	650	1250	0	None		—	—	3	1		Fill	62	50
212	14/1000	15/0730	11	36/27	18	18	90	76	0	10+	None	25	NA	0	280	1500	?	None			—	4	1		Fill	90	17
213	26/1000	27/0130	3	35/39	30	16	46	0	16	13	1100	27	30	9	580	1050	34	240	35	No	1010	4	14	25	24	39	50
JANUARY 1950																											
214J	1/2200	3/0730	0	47/47	20	37	35	65	11	6	450	35	25	—	---	—	-	93	30	Yes	1002	17	Filled		—	U	U
215	2/1000	3/0730	7	43/39	25	43	50	11	U	10	400	40	35	10	680	1650	18	52	U	NA	1004	12	18	15	U	44	40
216	2/2200	3/1930	12	41/39	25	23	50	11	20	18	750	35	44	14	815	1275	0	42	40	NA	999	11	13		Fill	113	12
217	3/2200	5/0130	11	32/36	17	12	63	24	25	20	550	38	55	18	1390	1200	−12	165	40	NA	1000	6	6		Fill	58	55
218	4/1000	5/1930	13	35/30	28	25	57	28	15	20	1800	35	40	10	1020	1300	0	30	U	No	992	7	11 in 6 hrs. 10	13	17	46	65
219	11/1000	12/0730	11	35/31	12	12	25	0	U	5	1550	30	NA	4	820	2700	0	U	U	No	994	3	5	6	6	30	30
220	16/1000	17/0730	13	38/29	16	23	90	38	0	12	·1250	37	NA	3	87	2100	40	78	50	No	992	3	5	Fill		18	26
221PF	17/1000	18/0730	11	44/35	22	35	49	68	10	7	500	38	28	−3	225	100	8	60	42	NA	1008	8	7	7	Fill	84	40
222	26/1000	28/0730	11	40/33	17	25	65	36	5	17	1850	40	NA	8	625	1900	20	U	U	No	992	6	6	5	5	Stationary	—
223	28/2200	30/1930	13	40/33	35	28	52	54	15	12	1100	44	45	5	310	1600	0	36	50	No	994	6	12	10 Jump	12	46	60
FEBRUARY 1950																											
224PF	31/1000	1/0130	10	41/35	18	23	20	25	10	4	450	33	NA	8	670	1600	0	U	U	NA	1019	5	4	5	7	Stationary	
225JPF	2/1000	3/0730	−8	38/44	20	17	55	55	10	7	1150	30	20	12	900	1550	46	75	40	No	1014	16	21	off map		60·	50
226PFN	7/1000	Neg.	—	40/	—	—	—	—	—	—	500			--	-			95	40	Yes	1010	—	--	—	—	—	—
227	8/1000	9/1330	11	36/32	15	18	31	28	13	6	500	25	NA	2	410	1250	10	60	50	NA	1011	2	3	4	7	35	20
228	12/2200	13/1930	13	31/30	20	25	17	30	U	8	550	26	25	12	1360	850	.	42	30	NA	1004	9	18	24	20	18	40
229	13/2200	15/0130	12	30/36	27	22	28	20	U	14	600	25	28	13	1280	800		15	43	NA	1005	6	13	15	19	65	31
230	17/1000	18/0730	2	44/44	40	28	55	28	5	11	550	27	23	2	62	750		60	80	NA	1013	15	15	16	21	90	34
231	21/1000	22/0130	6	36/37	25	18	53	70	10	3	400	23	33	5	425	700		150	22	NA	1003	12	14	17	17	59	34
232	22/1000	23/0730	3	31/39	25	18	40	58	9	9	950	33	35	10	1160	1050	32	45	30	NA	996	14	26	33	U	49	55
233J	23/1000	24/1330	−17	40/47	30	15	65	35	3	4	750	32	30	--	-			85	35	Yes	1000	14	15	22	23	75	26
234	25/1000	25/1930	5	37/35	18	14	81	102	1	Neg.	None	33	35	—	--	NA Flow		None		—	—	5	8	14	off map	90	35
MARCH 1950																											
235J	27/2200	1/1930	−18	42/47	40	25	45	65	9	5	800	10	25	—	-	--		103	28	Yes	998	16	25	22	22	15	20
236	1/1000	3/0130	16	32/25	20	18	U	80	U	2	1650	30	NA	11	500	1700	0	U	U	No	986	3	2	Filled		65	20
237	3/2200	5/0730	−5	30/35	12	8	45	85	U	27	1900	25	NA	2	150	1300	10	105	25	NA	992	5	4	Filled		65	12
238PF	6/2200	7/1930	8	41/32	30	20	10	40	20	8	500	15	17	4	240	650	---	53	10	NA	988	5	Filled		—	U	U
239	11/2200	12/1330	13	36/32	25	15	32	58	14	7	500	37	27	3	440	1500	30	121	22	NA	1002	7	12	10	—	52	65
240	14/1000	15/0730	15	28/26	18	15	45	15	10	8	None	17	27	5	530	1350	..	None		-	—	5	3	7	Fill	62	25
241J	15/1000	16/0730	7	29/32	20	12	45	0	10	9	800	23	23	—	--	--	-	90	45	Yes	1005	7	15	20	20	57	48
242J	18/1000	19/0730	8	34/35	40	23	50	50	7	6	300	25	22	—	—	—	—	79	25	Yes	1001	11	11	11	U	40	20
243	18/2200	20/0130	10	35/31	26	27	40	38	U	4	450	25	12	6	410	800	—	38	20	NA	1008	4	4	8 Jump	13	80	20
244J	19/1000	21/0130	−2	32/37	30	23	20	32	U	9	700	15	NA	—	—	--	—	84	20	Yes	1012	8	13	7	U	40	22
245	20/1000	21/0130	0	35/41	17	12	20	50	22	Neg.	700	16	13	5	530	250	—	110	40	NA	1002	4	6	10	12	80	25
246	20/2200	22/0730	7	35/34	30	20	47	55	4	8	600	17	25	7	530	900	—	55	10	NA	1011	5	13	19	20	32	30
247J	23/1000	24/1330	−2	37/43	45	13	20	50	8	4	450	10	30	—	—	—	—	88	18	Yes	994	6	Absorbed prev. storm			U	U
248J	26/2200	28/0130	−3	34/47	50	18	40	10	U	18	650	25	40	-	--	-	—	79	15	Yes	996	19	22	21	17	48	30
249	28/2200	28/1330	9	31/48	25	20	60	52	20+	15	2000	26	31	9	975	800	—	U	U	NA	986	9	14	25	U	43	32

J - Center Jump
N - Negative Case
S - Cold Tongue
C - Special Category Primary
F - Failure
PF - Partial Failure

APPENDIX I. Table 4.

850 MB CHART														FROM 500 MB CHART				FROM SURFACE CHART									
				INJECTION*			ORIENTATION		AMPLITUDE									PRIMARY STORM				NEW STORM INTENSITY					
Case No.	Date and Time of Injection	Date and Time of Cyclogenesis	Temperature at Time of C/G	Latitude (Inj C/G)	Average Wind Speed	Thermal Range	Contours	Isotherms	Contours	Isotherms	Distance C/ to Primary (Miles)	ΔT 1000 Miles NW	Geostrophic Wind	ΔT 1000 Miles (C°) East & West	Sharpness of Trough (Feet)	Distance to Trough (Miles)	Speed of Trough Past 12 Hrs (mph)	Course	Speed	Did 18 Hour Position Fall in CJ Circle	Central Pressure	P	P + 12 Hrs	P + 24 Hrs	P + 36 Hrs	Initial Course	12 Hour Speed
NOVEMBER 1950																											
301	1 1000	2 0730	13	38 37	25	18	55	30	8	13	950	22	44	6	490	800	—	69	40	No	1000	5	Bowling Green 7	4	Filled	72	23
302	2 1000	3 0730	13	39 30	17	22	65	55	3	13	1350	20	20	0	170	300	—	80	35	No	997	6	New Orleans 14	18	14	43	30
303	6 1000	7 1330	15	37 37	15	18	60	65	10	3	1000	15	15	0	140	0	—	59	22	No	1000	5	Tulsa 8	7	Filled	58	46
304[J]	8 1000	9 1330	−10	38 49	28	25	55	62	22	3	700	13	26	...	—	—	—	90	Erratic 25	Yes	1000	20	30	30	26	35	35
305	8 2200	10 0730	11	37 36	30	27	45	50	25	17	850	25	36	1	440	950	Fades	40	Erratic 30	No	998	RDU 4	4	Filled		Stationary	—
306	15 1000	None		40	35	13	50	45	15	15	250	21	45	—	—	—	—	58	34	NA	1002	None		—	—	—	—
307	16 2200	17 1930	7	36 41	20	11	50	30	12	13	1050	23	30	10	790	900	10	34	30	No	998	8	13	13	off map	90	15
308	19 1000	19 1930	10	42 38	20	26	40	40	15+	20+	1200	28	42	−2	350	500	—	30	36	No	982	15	25	19	15	68	47
309	20 1000	21 0130	5	34 42	30	28	45	25	11	13	1300	24	56	15	1300	1000	40	50	50	No	989	18	Boston 25?	31	22	32	32
310	22 2200	24 0130	3	43 36	35	35	60	80	5	5	650	30	15	5	370	100	—	Stationary		Knoxville Yes	1003	7	11	26	33	90	8
311[C]	U	27 1930												—	—	—	—	—	—	—	—	—	15	15	11	0	30
312	29 1000	30 0730	10	29 40	22	12	U	60	U	20	1300	19	30	20	Closed Low 1800	800	—	0	20	No	993	9	U	U	U	U	U
DECEMBER 1950																											
313	2 2200	3 1330	5	33 35	25	14	40	25	13	8	1250	25	40	8	775	975	36	48	20	No	1000	9	Atlanta 16	17	15	56	30
314	4/2200	6 0730	5	39 34	22	35	55	25	U	8	750	36	20	3	530	475	—	120	28	NA	999	11	Muscle Shoals 11	18	24	25	20
315[C]	U	8 0130												—	—	—	—	—	—	—	—	7	Baltimore 4	7	9	80	18
316	7 2200	9 0130	0	35 34	25	12	75	95	U	0	1100	20	25	6	990	200	—	0	35	NA	990	3	Birmingham 4	4	12	48	32
317	15 2200	17 0130	10	35 27	25	11	25	60	U	U	650	20	NA	2	470	150	—	60	40	NA	1002	1	4	10	16	Stationary	—
318	16 2200	17 0730	10	27 26	18	13	90	85	2	2	None	20	13	1	430	450	—	—	None	—	—		26½°–85° See above			—	—
319	19/2200	20/1930	0	40/34	25	11	90?	U	U	U	500	18	13	9	875	500	—	140	30	NA too fast	1023	8	34°–70° U	off map		50	35
320	25/2200	27/0130	8	42/34	28	34	75	90	5	1	650	37	32	Negative Develop.			—	77	60	No	1008	7	Columbia, S. C. Filled		—	135	60
321	26/1000	27/0730	9	37 31	30	33	80	75	U	1	1100	31	NA	2	490	2200	15	70	60	No	1007	4	Albany, Ga. Filled		—	U	U
322	26/2200	28/0130	8	36/32	22	28	62	68	U	2?	1700	35	NA	3	480	2500	20	70	60	No	1000	3	31°–72° Filled		—	U	U
323	27/1000	28/0730	12	32/26	16	20	75	65	U	3	None	25	NA	0	190	1100	10	None		—	—	3	26°–90° 3 Filled		—	38	20
324	27/2200	29/0130	1	35/35	20	17	U	90	U	2	None	21	NA	1	560	1150	0	None		—	—	4	Hatteras 8	16	7	22	24
325	29/1000	30/0730	10	35/32	15	11	62	95	U	U	None	17	NA	4	320	1150	0	None		—	—	3	3	11	11	Brunswick, Ga. 52	30
JANUARY 1951																											
326	1/2200	2/1930	−2	28/44	25	15	20	10	20	17	300	25	33	8	930	975	10	55	31	NA	1000	11	9	11	off map	58	50
327	2/2200	3/0730	6	30/40	35	17	40	20	18	15	1550	30	40	7	870	450	—	58	50	NA	999	8	15	16	15	48	30
328[F]	3/2200	None	—	33/	30	15	50	60	14	3	1450	30	48	—	—	—	—	70	44	No	995	—	None		—	—	—
329	5/1000	6/0130	1	40/41	25	22	65	75	5	2	400	28	20	2	530	1100	0	Filled		—	1013	11	Goshen, Ind. 11	6	3	72	50
330	6/1000	6/1930	8	33/32	22	18	45	30	10	6	1600	22	15	6	400	900	28	72	50	No	1016	9	Jackson, Miss. 9	16	22	57	46
331	8/1000	9/0730	11	23/26	22	20	100	30	U	11	2100	27	13	8	910	1250	46	57	46	No	986	U	off map but a major southern U Lat. storm moving East				

APPENDIX I. Table I (Concluded)

	INJECTION							[illegible]				FROM 500 MB CHART						FROM SURFACE CHART									
																		PRIMARY STORM				NEW STORM INTENSITY					
Case No.	Date and Time of Injection	Date and Time of Cyclogenesis	Temperature at Time of C.G.	Latitude Inj./C.G.	Average Wind Speed	Thermal Range	Confidence	[illegible]	[illegible]	[illegible]	Distance C.G. to Primary (Miles)	5/7 1000 Miles NW	Geostrophic Wind	5/7 1000 Miles East & West	Sharpness of Trough (Feet)	Distance to Trough (Miles)	Speed of Trough Past 12 Hrs (mph)	Course	Speed	Did 18 Hour Position Fall in CJ Circle	Central Pressure	P	P + 12 Hrs	P + 24 Hrs	P + 36 Hrs	Initial Course	12 Hour Speed
									JANUARY 1951 (Cont.)																		
332J	9/2200	11/0130	0	37/42	30	15	50	50	9		[illegible]	21	17					80	28	Yes	1008	8	8	17	30	73	36
333J	10/2200	11/1930	2	34/42	30	13	50	50	[illegible]	10	[illegible]	30	15					73	36	Yes	1011	8	16	28	30	80	34
																							Little Rock				
334	12/2200	14/0130	9	27/35	20?	15	20	0	1	10	400	15	NA	11	590	1100	22	150	40	NA	1007	13	15	16	26	60	25
																							40°-90°				
335	19/2200	20/0730	11	39/40	25	21	64	42	13	8	350	28	40	12	600	2100	20	58	35	NA Borderline	1002	17	23	22	24	58	40
336	22/2200	23/1930	9	36/31	22	17	35	70	15	2	1000 300	22	NA	N.W. Flow				90	20	No	1002		32°-90°	Jump			
337J	23/2200	24/1930	7	33/35	22	12	35	35	18	5	450	20	NA					105	30	NA	1005	3	3	3	6	90	25
																		90	25		1015	4	8	11	9	50	21
																							Little Rock Jump				
338PF	26/2200	28/0130	7	41/35	33	40	70	70	5	2	600	31	40	1	75	1250	0	90		Fill.	1003	9	12	10	7	57	60
339J	27/2200	29/0130	7	37/41	25	30	60	50	6	8	350	33	25					57			1011	10	7	off map		65	50
																					c.i. fest	Roanoke					
340	28/1000	29/0730	9	37/37	17	30	65	51	7	11	950	45	26	5	455	1750	Fades	57	60		1016	9	4	Filled		160	15
																							27°-93°				
341	28/2200	29/1930	7	36/27	15	30	70	55	8	11	1600	40	NA	0	280	2400	0	65	50		1017	3	Filled		—	U	U
																						Selma, Ala.					
342PF	30/2200	31/1330	11	26/33	25	15	U	45	1	7	400	30	20	13	1330	1600	38	140	15	NA	1001	10	14	—	—	40	50
									FEBRUARY 1951																		
																							27°-73°				
343	1/2200	2/1930	14	26/27	25	25	45	30	16	25	1900	35	NA	4	790	1750	32	45	40	N.		8	16	16	16	39	24
																						46° 88°					
345	5/2200	6/1330	5	46/46	25	30	25	80	19	2	800	30	24	0	360	650	—	75	35	No		19	20	14	30	76	35
346J	6/1000	7/0730	3	35/38	25	30	30	60	18	3	950	25	35			—	—	76	35	Yes?		16	25	30	32	52	46
347	8/2200	9/1330	5	36/31	28	20	72	80	1	1	600	30	20	N.W. Flow		—	—	180	U	No	1015	4		Filled	—	U	U
348	10/2200	11/1930	18	38/37	18	13	82	0	1	22	900	35	30	Negative		—	—	140	25	NA	1002	12	12	12	11	198	15
349	10/2200	11/1330	5	29/38	15	12	1	45	1	8	None	22	NA	7	630	450	—	—	None	—	—	10	7	off map		80	30
350	13/1000	14/0730	8	38/30	22	25	1	58	1	10	None	30	NA	6	590	1000	0	—	None	—	—	7		Filled	—	U	U
351	14/1000	15/1330	8	24/32	25	18	1	20	1	17	None	21	NA	10	1040	750	12	—	None	—	—	6	12	10	4	15	35
352	16/1000	17/0730	3	32/35	25	11	20	10	19	13	None	11	40	2	450	650	—	—	None	—	—	2	3	4	—	20	30
353	18/2200	19/1930	12	27/34	25	17	35	0	40	25	900	12	15	3	840	900	26	200	35	NA	1	11	16	21	17	70	23
354J	20/1000	21/1330	7	30/37	40	10	30	0	1	7	450	20	40			—	—	67	30	Yes	997	16	20	26	25	90	30
																				NA		39°-74°			off		
355	28/2200	1/1930	5	42/39	40	22	1	0	1	6	250	22	31	5	410	1250	Fades	60	27	Yes	1000	4	12	22	map	80	30
									MARCH 1951																		
																						39°-75°					
356	3/1000	4/0730	−4	33/39	30	18	55	30	1	17	1100	22	46	Negative			—	38	30	NA	989	5	5		Filled	78	18
																						32°-88°					
357	4/1000	5/0130	12	31/32	20	16	55	50	1	9	2000	22	26	6	320	1100	Fades	U	U	NA	988	3	Filled		—	U	U
																						40°-90°					
358	6/1000	6/1930	13	48/40	40	25	35	20	U	20	500	35	26	Negative		–	—	Stationary			1001	9	9	Filled		64	56
		8/1330	−5	38/44																	43-60	8	18	off map		—	
359S	7/1000	8/0730		36	30	11	65	0	2	5	1000	25	22	Negative		...	—	90	50	No Filling	1000	6	5	Filled		146	15
																							Miss.				
360	10/2200	11/1330	14	37/34	30	25	20	55	U	5	800	25	NA	4	230	1250	30	160	U	NA	1010	12	10	9	16	U	U
361	11/1000	12/0130	10	35/30	22	25	1	10	1	6	600	22	NA	1	300	1200	0	40	25	NA	1014	6	6	10	13	90	18
																							27°-93°				
362	17/2200	19/0130	15	36/27	22	25	38	20	U	11	550	25	25	2	370	900	Backs up?	350	30	No	1005	6	9	13	12	40	30
363	20/2200	21/1930	−3	40/39	22	12	80	70	3	20	None	26	13	14	920	900	30	None		—	—	8	7	—	—	53	30
																						45°-68°			off		
364	23/2200	24/1930	−1	32/45	22	21	68	48	U	9	1150	30	30	9	600	1100	26	60	29	No	989	11	17	20	map	0	28
																						40°-88°					
365	28/2200	29/1330	5	30/40	27	16	15	15	3	3	725	33	28	12	840	750	20	20	U	NA	999	12	14	13	16	8	30
																						40°-78°					
366	29/1000	30/1330	10	29/40	30	16	25	23	U	23	1000	33	28	13	1140	1050	20	0	30	No	999	14	7	12	8	70	30

APPENDIX [illegible] Table 5

Center Jump
[illegible]egative Case
[illegible] Tongue
Category Primary
F [illegible]re
PF [illegible]

	850 MB CHART			INJECTION			ORIENTATION		AMPLITUDE					FROM 500 MB CHART				FROM SURFACE CHART										
																		PRIMARY STORM				NEW STORM INTENSITY						
Case No.	Date and Time of Injection	Date and Time of Cyclogenesis	Temperature at Time of C.G.	Latitude Inj. C.G.	Average Wind Speed	Thermal Range	Contours	Isotherms	Contours	Isotherms	Distance C.G. to Primary (Miles)	27 1000 Miles NW	Geostrophic Wind	27 1000 Miles C.G. East & West	Sharpness of Trough (feet)	Distance to Trough (Miles)	Speed of Trough Past 12 Hrs (mph)	Course	Speed	2nd 18 Hour Position Fall in CJ Circle	Central Pressure	P	P + 12 Hrs	P + 24 Hrs	[illegible] Hrs	[illegible]	Initial [illegible]	12 Hour Speed
NOVEMBER 1951																												
401	1/2200	2/1330	11	37/30	22	25	U	65	1	30	None	33	NA	3	276	1000	34	None			—	7	16	[illegible]		30	45	45
[illegible]F	4/1000			36/[illegible]	25	17	U	50	1	U	850	28	25	10		500		50			1004	—					—	—
	4/2200	5/1330	16	40/32	23	17	48	120	9	Neg	500	23	20		Negative			100	15	NA	1007	16			19	18	70	32
	6/1000	6/1930	10	28/33	35	19	0	5	22	9	900	22	35	6	1326	600		40	30	NA	1007				14	13	35	56
	11/0130	15/0130			CJ follows at 0130 15				no C.G.																—	—	—	—
	[illegible]2200	15/1330	10	35/34	20	15	60	90	15	0	None	22	20	7	836	0		None			None			12	14	10	75	55
	[illegible]	17/0130	15	33/36	21	26	40	10	13	15	2250	28	30	5	910	1000	0	55	55	N.			8	13	15	15	38	65
		19/1930	7	35/30	22	15	41	35	12	15	None	22	23	20	1541	1050	0		None				10	11	16	off	31	27
40[illegible]		22/1930	4	36/45	25	18	15	0	10	0	1400	22	40	5	600	1250	0	40	1	No			12	9	Filled		55	64
409		[illegible]/1330	12	39/[illegible]	22	22	1	1	1	1	None	33	NA		Negative		—			N.			—	—	—	—	—	—
410	[illegible]		−4	51/41	25	12	35	40	16	10	900	NA	NA				—	40	45			1012	—	—	—	—	—	—
411J	25/[illegible]		7	33/27	15	15	90	60	0		2200	23	NA	2	186	850	40		NA			970	3	3	Filled		—	—
412	27/10[illegible]		[illegible]	32	15	15	70	75	8	1	None	15	NA	8		0	0		None			—	5	16	28	20	50	—
413	28/1000	29/[illegible]																										
DECEMBER 1951																												
					30	20	31	8	1	27	1000	20	25	15	750	750	1				No	968	3	4	20	20	78	37
414	1/2200	2/1330		16	50		U	22	1		1500	17	25	5	444	700				NA	No	985	7	6	4	Fill	55	20
415F	3/2200	4/1330		15		19	29	29	1	27	1400	20	NA	12	1194	15				NA	No	990	3	9	8	16	40	65
416	7/1000	8/1330		13	36/[illegible]	15	80	40	1	11	1540	22	NA	10	666	—			NA	NA	No	1005	4	Filled		—	95	24
417	9/1000	11/0130		2	32/[illegible]		66	70	3	5	NA	21	23	12	1700					None			12	9	14	off	64	31
418	11/1000	12/0130		0	31/40		56	14	12	6	[illegible]	35	40						28	65	No	1001	—		—	—	—	—
419NF	14/1000				36	30		63		2	1000	25	13					0	90	6	Yes	1010	10	26	Sec.		75	40
420	16/2200	17/1930		−12	36	20		[illegible]	1	2	6	25	25				200	27	74	40	Yes	1006	[illegible]	[illegible]	34	off	53	42
421	17/2200	18/1330		−10	39/41	35	33	16			600	25	50						55	1	NA	1011	2	11	17	off map	57	33
422	25/1000	25/1930		0	39/38	25	23	42			[illegible]			1			1000	1		None		—	12		off map		—	—
423	26/2200	27/1930		−11	33	25	27	67																				
JANUARY 1952																												
424	2/1000	3/0130		10	36/38	16	15	90	68	0	[illegible]	None	40	NA	12	840	1000	18		None		—	6	3	off	—	80	48
425	2/2200	4/0130		11	24/36	U	16	U	46	U	[illegible]	None	25	NA	12	1022	1400	0		None		—	5	9	13	Sec.	57	40
426	4/1000	5/0130		1	33/37	28	15	50	45	12	7	850	10	24	2	[illegible]	1000	10	57	40	NA	1012	5	[illegible]	21	off	46	32
427	5/1000	6/0130		7	35/34	35	18	70	70	U	2	1000	20	30	15	908	1250	45	46	32	NA	1008	6	13	23	25	72	35
428	8/1000	9/1930		7	37/35	16	30	42	43	U	11	750	15	40	17	962	1000	18	42	18	NA	1003	10	16	21	40	72	35
429FF	17/1000	18/1330		2	39/48	30	15	52	49	8	13	1100	25	17	13	720	1200	50	35	38	No	989	3	2	off map		U	U
430S	21/2200	23/1330		—	—	—	—		—	—									77	30	Yes	991			—	—	—	—
431	26/2200	27/1930		8	34/39	15	15	72	44	U	7	None	35	30	10	476	800	39		None			—	[illegible]	13	21	45	60
FEBRUARY 1952																												
432J	1/2200	2/1930		5	33/27	25	12	175	U	1	1	100							100	22	Yes	1012	—	—	—	—	—	—
433J	10/1000	11/1330		−9	40/40														92	35	Yes	988			—	—	—	—
434F	14/1000	15/1330		13	24/28	U	15	U	42		14	None	20	12	10	1000	1100	32	None				[illegible]		[illegible]	Jump	60	23
435J	15/2200	16/1930		6	27/36														63	25	Ye	1005			—	—	—	—
436	18/2200	19/1930		0	31/40	22	18	37	43	[illegible]	12	900	25	26	7	670	1200	0	27	23	NA	1000	[illegible]	14	Fill		90	20
437	19/2200	20/1930		5	35/35	25	20	30	41	[illegible]	8	600	17	21	7	444	1000	50	65	20	No	1000		8	18	16	74	29
438	22/1330	23/0130		12	35/28	15	17	34	66		5	None	20	15	1	450	1000	0	—	None		—	3	3	8	10	90	60?
439	24/1000	25/1930		12	37/27	20	18	U	90	U	2	450	20	NA	5	930	700	0	132	25	NA	1000	10	13	14	22	78	30
440J	29/1000	1/0730	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
MARCH 1952																												
441N	2/2200	—		—	28/	18	17	32	55	18	18	600	[illegible]	—	—	—	—	—	—		—	997	—	—	—	—	—	—
442	3/1000	4/0730		5	30/36	30	25	41	14	20	10	650	[illegible]	23	15	1741	1500	22	55	25	NA	990	6	13	15	15	350	15
443J	9/1000	10/0730		11	27/31	U	18	22	48	1	14	900	13	36	12	—	1300	38	75	40	Yr	995	13	21	22	23	46	40
444J	12/1330	13/1330		2	37/40	40	15	52	25	[illegible]	9	500	20	35	5	—	1300	31	77	22	Yes	983	14	12	28	32	90	55
445	14/1000	15/0130		13	34/	23	20	100	645	6	3	16	24	25	[illegible]	—	[illegible]	—	—	—	No	940	4	7	13	Filled	70	23
446F	18/1000	19/1330		2	30/35	40	18	10	[illegible]	11	7	950	8	35	8	13.[illegible]	1000	28	50	22	NA	[illegible]	[illegible]	15	7	7	90	25
447	22/1000	23/0730		12	30/38	28	30	39	[illegible]	17	20	850	20	32	16	1100	1000	0	30	20	NA	997		8	7	13	U	U
448	25/1000	26/1330		10	36/33	25	13	59	[illegible]	5	4	None	20	14	11	1092	1600	0	—	None	—	—	3	6	5	7	U	U
248J	26/2200	28/0130		−3	34/47	50	18		10	U	18	650	25	40	—	—		—	70	15	Yes	996	19	22	21	17	48	30
249	28/2200	28/1330		9	31/43	25	20		52	20+	15	[illegible]	26	31	9	975	800	—	[illegible]	U	NA	986	9	11	25	U	43	32

APPENDIX I. Table 5 (Concluded)

	850 MB CHART													FROM 500 MB CHART				FROM SURFACE CHART									
				INJECTION			ORIENTATION		AMPLITUDE									PRIMARY STORM				NEW STORM INTENSITY					
Case No.	Date and Time of Injection	Date and Time of Cyclogenesis	Temperature at Time of C/G	Latitude (In) C/G	Average Wind Speed	Thermal Range	Contours	Isotherms	Contours	Isotherms	Distance C/ to Primary (Miles)	ΔT 1000 Miles NW	Geostrophic Wind	ΔT 1000 Miles (C°) East & West	Sharpness of Trough (Feet)	Distance to Trough (Miles)	Speed of Trough Past 12 Hrs (mph)	Course	Speed	Did 18 Hour Position Fall in CJ Circle	Central Pressure	P	P + 12 Hrs	P + 24 Hrs	P + 36 Hrs	Initial Course	12 Hour Speed
CASES IN WHICH NO CYCLOGENESIS OCCURRED NOVEMBER 1951																											
449	3 1000										500										994						
450	3 2200										580										997						
451	12 2200										1100										985						
452	13 1000										500										982						
453	21 1000										1200										988						
454	26 2200										1300										976						
DECEMBER 1951																											
455	2 2200										500										995						
456	3 1000										600										987						
457	5 1000										840										984						
458	6 1000										1200										980						
JANUARY 1951																											
459	18 2200										800										994						
MARCH 1951																											
460	10 1000										600										990						
461	12 2200										400										984						
462	18 1000										700										988						

APPENDIX II. Table I. Category I cyclones — origin

Case No.	Year	Date	Month	Time (EST)	Hours Before Filling	Origin of Cyclone
1	1947	10	Nov	2200	36	GA
2		22	Nov	2200	N	N-S
3		23	Nov	2200	18	M
4		26	Nov	1000	24	GA
5		11	Dec	1000	18	GA
6		26	Dec	1000	N	M
7	1948	14	Jan	1000	N	N-S
8		17	Jan	1000	18	N-S
9		19	Jan	1000	N	N-S
10		21	Jan	2200	12	GA
11		22	Jan	2200	18	N-S
12		(Case discarded from original data sample)				
13		29	Mar	1000	N	N-S
14		19	Dec	1000	24	GA
15		19	Dec	2200	N	M
16	1949	12	Jan	2200	N	N-S
17		8	Feb	2200	48	M
18		6	Mar	2200	36	M
19		14	Mar	1000	6	CG
20		3	Nov	1000	30	N-S
21		14	Nov	1000	12	CG
22		15	Nov	2200	18	M
23		18	Nov	1000	18	M
24		18	Nov	2200	N	CG
25		21	Nov	2200	N	M
26		23	Nov	2200	N	N-S
27		25	Nov	2200	36	M
28		30	Nov	1000	N	CG
29		5	Dec	2200	18	GA
30		22	Dec	1000	24	M
31		25	Dec	1000	30	M
32	1950	19	Jan	2200	12	GA
33		21	Feb	2200	42	GA
34		24	Feb	1000	18	GA
35		3	Mar	2200	N	GA
36		13	Mar	2200	36	CG
37		15	Mar	2200	N	GA
38		30	Mar	2200	N	CG
39		5	Nov	1000	N	M
40)		6	Nov	2200	N	GA
41)		7	Nov	1000	N	GA
42		10	Nov	2200	18	N-S
43)		21	Nov	1000	N	GA
44)		21	Nov	2200	N	GA
45		19	Dec	2200	30	M

APPENDIX II. Table 1. Category I cyclones — origin (Concluded)

Case No.	Year	Date	Month	Time (EST)	Hours Before Filling	Origin of Cyclone
46)		11	Dec	1000	18	M
47	(Vicinity RAP)	12	Dec	2200	30	CG
48	(Vicinity XD)	12	Dec	2200	N	GA
49)		17	Dec	2200	36	GA
50)		18	Dec	1000	24	GA
51)		20	Dec	2200	N	GA
52)		21	Dec	1000	N	GA
53)		24	Dec	2200	N	GA
54)		25	Dec	1000	N	GA
55		27	Dec	2200	24	CG
56)	1951	25	Jan	1000	N	GA
57)		25	Jan	2200	42	GA
58		2	Feb	2200	N	GA
59)		7	Feb	2200	30	GA
60)		8	Feb	1000	18	GA
61		10	Feb	1000	48	GA
62)		21	Mar	2200	N	M
63)		22	Mar	1000	N	M
64		24	Mar	2200	30	CG

Parenthesis beside case number indicates same original cyclone in successive 12-hour positions.

N signifies nonfilling system.

Abbreviations for the four modes of origin are: GA — forms in NW-SE trough from Gulf of Alaska cyclone; N-S — forms in N-S trough extending south from Arctic Circle. M — cyclone moves in intact; CG — apparently pure cyclogenesis, not associated with clear trough or mother low.

APPENDIX II. Table 2. Category I cyclones — development

Case No.	Instability Contrast	850 mb Advective Term	Half Wavelength	Amplitude	Stage 1	Stage 2	Hours Before Filling Actual	Hours Before Filling Forecast
(a)	(b)(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
1	8	−5	31	28	5.4	2.7	36	48
2	−(k)	2	30	23	—	2.9	N	—
3	8	6	28	(30) (m)	2.1	2.3	18	18
4	7	−2	35	27	3.1	3.4	24	36
5	9	1	32	14	3.6	3.2	18	36
6	—	(1)	26	27	—	2.1	N	—
7	13	0	40	32	5.3	3.3	N	N
8	5	1	38	26	0.7	4.2	18	30
9	15	(0)	35	28	5.2	3.2	N	N
10	4	−2	31	29	1.2	2.7	12	18
11	—	1	38	26	—	4.2	18	—
13	13	0	45	24	5.3	>5	N	N
14	—	(−3)	—	—	—	—	24	—
15	13	0	38	14	5.3	4.2	N	N
16	11	−4	(40)	21	7.0	5.0	N	N
17	7	−7	28	10	5.4	2.2	48	36
18	9	−2	(41)	(35)	4.7	3.0	36	42
19	9	0	20	11	4.0	0.5	6	12
20	8	0	25	25	3.0	2.1	30	18
21	6	−2	25	18	2.2	2.1	12	12
22	6	3	23	28	0.8	1.7	18	6
23	6	−3	31	24	3.0	3.0	18	30
24	4	−7	38	28	4.2	3.8	N	N
25	10	−3	32	(35)	6.0	2.4	N	N
26	10	−3	32	19	6.0	3.3	N	N
27	9	−4	28	19	5.7	2.7	36	N
28	10	−1	30	16	5.0	3.0	N	48
29	8	−6	17	7	5.8	0.0	18	18
30	9	0	32	19	4.0	3.3	24	42
31	7	0	Over 50	(30)	2.1	4.2	30	36
32	9	9	24	7	2.5	1.0	12	12
33	6	(−4)	30	17	3.7	3.0	42	36
34	7	−6	23	10	5.0	1.1	18	18
35	5	−6	38	14	4.2	4.2	N	N
36	8	−2	45	(28)	4.2	4.6	36	N
37	14	−2	45	13	5.5	4.8	N	N
38	13	−4	38	18	5.8	4.7	N	N
39	6	−7	33	15	4.7	3.5	N	N
40	5	−2	47	19	1.5	>5.0	N	N
41	(6)	−3	35	21	3.0	4.0	N	42
42	4	−1	30	20	0.8	2.5	18	12
43	11	−2	25	16	5.9	2.0	N	42
44	(6)	−5	47	17	4.2	>5.0	N	N

APPENDIX II. Table 2 Category I cyclones — development (Concluded)

Case No.	Instability Contrast	850 mb Advective Term	Half Wavelength	Amplitude	Stage 1	Stage 2	Hours Before Filling Actual	Hours Before Filling Forecast
(a)	(b)(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
45	9	−2	26	30	4.6	2.1	30	30
46	7	0	28	29	2.1	2.4	18	18
47	2	0	38	20	1.1	4.7	30	42
48	11	−2	33	29	5.9	2.8	N	N
49	7	−2	32	22	3.0	3.2	36	30
50	5	−5	30	24	3.6	2.8	24	30
51	10	1	33	15	4.2	3.5	N	48
52	(8)	−4	36	9	4.9	3.3	N	N
53	5	−7	37	21	4.4	4.4	N	N
54	(13)	−3	37	20	5.8	4.5	N	N
55	6	−7	27	11	4.8	2.0	24	30
56	7	−8	27	17	5.7	2.3	N	42
57	10	−6	29	17	>7.0	2.8	42	N
58	11	0	33	5	5.0	2.9	N	48
59	18	5	33	17	3.7	3.5	30	42
60	17	−8	36	16	3.5	4.1	18	N
61	12	−5	20	4	6.5	0.0	N	18
62	14	−3	37	16	5.5	4.2	N	N
63	12	−11	48	17	5.6	>5.0	N	N
64	9	1	30	14	3.6	2.9	30	30

(a) See Appendix II Table 1 for dates of cases.
(b) Cross-section line perpendicular to 700-mb flow over low center.
(c) Maximum Instability Index minus Minimum Instability Index. The maximum is always towards warm air from the minimum.
(d) Temperature at point 24 hours travel at geostrophic speed up-contour minus temperature at low center, at 850 mb.
(e) Measured in degree latitude at 700 mb along the parallel crossing the low center from the ridge line west of the low to the trough line east.
(f) Maximum latitude difference of the 700-mb contour over the low from the ridge west of the low to the trough east.
(g) See Fig. 38.
(h) See Fig. 39.
(i) N signifies Non-filling System.
(j) See the Composite Graph, Fig. 41.
(k) Not entered in graph. Data missing. Estimates unreliable.
(m) In parenthesis. Some data missing. Estimates believed correct.

APPENDIX II. Table 3. Category I cyclones – movement

Case No. (a)	Hours Before Filling (i)	SPEED: Geo. Wind at 700 mb (n)	Dist. E to Cold Tongue (p)	Max. Temp. Diff. in NE Quad. (q)	Actual Speed in k. (r)	Fcst Speed (x)	DIRECTION (s): Actual	Fcst	RECURVATURE: Temp. Over Low at 700 mb. (t)	Max. Temp. Diff. Down-stream (u)	Stage 3 (v)	Stage 2 (h)	Time of Recurvature (w): Actual	Fcst
1	36				20	MTNS		MTNS						MTNS
2	N	—(k)	10	(14)(m)	33	28	S	S	−14	6	3.5	2.9	NR	NR
3	18	—			39	F-18	10 R	F-18	−15	6	3.2	2.3	NR	NR
4	24	42			38	42	20 L	S	−11	4	3.7	3.4	NR	NR
5	18	22			32	F-18	S	F-18	−15	3	2.6	3.2	NR	NR
6	N	28	12	(16)	29	31	S	S	−16	4	2.6	2.1	NR	NR
7	N	35	17	21	35	38	S	S	−15	10	4.0	3.3	30	30
8	18	25			50	F-18	40 R	F-18	−13	11	4.7	4.2	NR	NR (24)
9	N	35	12	17	29	32	S	S	−14	10	4.3	3.2	30	30
10	12	63			75	F-12	(S)	F-12	− 8	2	3.8	3.7	NR	NR
11	18	22			43	F-18	30 R	F-18	−17	0	1.7	4.2	NR	NR
13	N	(25)	10	17	36	31	30 R	S	−10	10	5.0	>5	24	24
14	24	—			18		10 R	S	−15	11	4.2		NR	NR (30)
15	N	—	—	8	34		S	S	−21	1	1.0	4.2	NR	NR
16	N	35	(22)	22	43	43	S	S	− 6	4	4.6	5.0	NR	24
17	48	38	11	17	34	31	S	S	−15	5	3.0	2.2	NR	NR
18	36	35			34	35	S	S	− 5	16	7.2	3.0	18	18
19	6					MTNS		MTNS						MTNS
20	30	28			30	28	20°R	S	− 6	8	5.4	2.1	NR	NR (24)
21	12	24				F-12	30°L	F-12	1	0	5.3	2.1	NR	NR (24)
22	18	(20)			44	F-18	10°R	F-18	−12	3	3.2	1.7	NR	NR
23	18	(28)			37	F-18	S	F-18	− 5	15	7.0	3.0	NR	NR (18)
24	N	45	17	23	49	41	S	S	0	14	7.8	3.7	12	12
25	N	35	15	24	34	40	S	S	− 5	20	8.0	2.4	18	18
26	N	45	16	22	41	39	S	S	− 7	3	4.2	3.3	18	30
27	36	(35)			31	(35)	S	S	− 8	7	4.8	2.7	NR	30
28	N				29	MTNS		MTNS						MTNS
29	18	(25)			25	F-18	S	F-18	−11	7	4.2	0.0	NR	NR (30)
30	24	38			33	38	S	S	−11	9	4.6	3.3	NR	NR (30)
31	30	(20)			23	(20)	S	S	−17	6	2.9	4.2	NR	NR
32	12					MTNS		MTNS						MTNS
33	42	25			22	25	S	S	−18	2	1.8	3.0	NR	NR
34	18	36			54	F-18	20°R	F-18	− 6	4	4.5	1.1	NR	NR (30)
35	N	20	25	22	38	44	S	S	− 8	18	7.0	4.2	18	12

APPENDIX II. Table 3. Category I cyclones — movement (Concluded)

		SPEED					DIRECTION		RECURVATURE					
Case No. (a)	Hours Before Filling (i)	Geo. Wind at 700 mb (n)	Dist. E to Cold Tongue (p)	Max. Temp. Diff. in NE Quad. (q)	Actual Speed in k. (r)	Fcst Speed (x)	Actual (s)	Fcst (s)	Temp. Over Low at 700 mb. (t)	Max. Temp. Diff. Downstream (u)	Stage 3 (v)	Stage 2 (h)	Time of Recurvature Actual (w)	Time of Recurvature Fcst (w)
36	36	30			33	30	S	S	−28	2	0.0	4.6	NR	NR
37	N	28	27	14	33	33	S	S	−11	3	3.5	4.8	NR	NR
38	N	30	17	20	—	37	S	S	0	10	7.0	4.7	6	6
39	N	34	12	14	23	29	S	S	− 5	9	5.9	3.5	24	24
40	N	25	13	10	20	25	S	S	−10	1	3.2	>5	NR	NR
41	N	22	8	6	17	20	S	S	(−14)	(0)	2.2	4.0	NR	NR
42	18	36			29	F-18	30°R	F-18	−12	3	3.2	2.5	NR	NR
43	N	35	16	20	35	37	(S)	S	(−10)	(3)	3.7	2.0	NR	NR
44	N	20	13	13	20	28	(S)	S	−10	4	3.9	>5	NR	30
45	30	40			40	40	S	S	− 6	8	5.5	2.1	NR	NR (24)
46	18	28			31	F-18	S	F-18	− 8	0	3.5	2.4	NR	NR
47	30	32			28	32	10°L	S	−10	0	3.0	4.7	NR	NR
48	N	20	15	6	23	23	(S)	S	−14	0	2.2	2.8	NR	NR
49	36	27			33	27	S	S	− 8	2	3.7	3.2	NR	NR
50	24	28			28	28	S	S	−10	0	3.0	2.8	NR	NR
51	N	35	22	22	40	43	S	S	−10	8	4.6	3.5	36	30
52	N	42	19	23	42	42	S	S	− 9	12	5.7	3.3	24	24
53	N	38	19	28	51	47	20°R	S	− 5	7	5.5	4.4	18	24
54	N	40	20	28	—	47	S	S	2	11	7.7	4.5	6	6
55	24	30			26	30	S	S	−10	0	3.0	2.0	12	NR
56	N				18	MTNS		MTNS						MTNS
57	42				24	MTNS		MTNS						MTNS
58	N	38	19	23	40	42	10°R	S	−12	7	4.0	2.4	18	30
59	30				30	MTNS		MTNS						MTNS
60	18				29	MTNS		MTNS						MTNS
61	48	48	28	29	37	51	20°R	S	− 2	10	6.6	0.0	NR	24
62	N	32	15	18	33	34	40°R	S	−10	7	4.4	4.2	24	24
63	N	32	21	18	35	37	30°R	S	0	5	6.0	>5	12	12
64	30	34			37	34	S	S	− 8	0	3.5	2.9	NR	NR

(a), (h), (i), (h), (m) — Legend same as Appendix II Table 2.
(n) Measured geostrophic wind in knots over low center at 700 mb.
(p) Distance in degrees latitude from low center along latitude line east to center of isotherm trough at 700 mb.
(q) Difference in degrees C. between temperature over low center and lowest temperature within 1000 miles in Northeast quadrant from low at 700 mb.
(r) Average speed in knots for 24 hours or until time of recurvature if earlier. Short-duration cases not forecast; see text
(s) "S" refers to Steer. See text for definition. Deviations shown by angle of departure from steering current; R-right, L-left. Short duration cases not forecast; see text.
(t) Temperature in degrees C. over low center at 700 mb.
(u) Difference in degrees C. between temperature over low and lowest temperature met in moving downstream along contour to major trough.
(v) See Fig. 51.
(w) Time in hours until recurving. See text for definition. NR-non-recurving within 30-hour period. Values in parentheses indicate recurvature forecast time but after time of filling of cyclone.
(x) MTNS signifies cyclone located in mountain area at zero-time; see Fig. 12. No forecast made; see text for general movement features.

APPENDIX III. Category I and Category II cyclones — control data sample

Development and Movement Parameters and Forecast

(Data tabulated herein is presented in condensed form. Parenthetical letters refer to legend-comments on Tables 1, 2 and 3 of Appendix II.)

Case No.	Date	(c) (d)	(e) (f)	Stages 1 2	Hours Before Filling Actual	Hours Before Filling Fcst.	(n)	(p) (q)	Speed Actual	Speed Fcst	Direction Actual	Direction Fcst	(t) (u)	Stage 3	Time of Recurvature Actual	Time of Recurvature Fcst
65}	1951 2 Nov 1000E	8 −9	22 22	6 5 1 5	N	36	34	10 21	36	34	S	S	−10 15	6 0	30	24
66}	2 Nov 2200	17 −9	26 (25)	4 3 2 2	12	24	(35)		29	(35)	S	S	−15 12	4 3	12	30
67} TWIN	3 Nov 2200	6 −3	28 17	3 0 2 5	18	24	34		37	F-18	10 R	F-18	−2 6	5 8	NR	NR 24
68}	3 Nov 2200	12 0	30 27	2 2 3 0	N	N	40		20	MTNS		MTNS				MTNS
69	4 Nov 1000	9 0	38 21	4 0 4 9	N	N	30		10	MTNS		MTNS				MTNS
70	14 Nov 1000	10 0	36 20	4 6 4 3	N	N	42		9	MTNS		MTNS				MTNS
71 II	27 Nov 1000	3 0	34 15	0 8 3 7	6	24	25			F-6	—	F-6	−9 6	4 3	NR	NR 40
72	29 Nov 2200	7 0	18 3	2 2 0 0	6	6	30			F-6		F-6	−11 0	2 3	NR	NR
73}	11 Dec 1000	4 1	36 25	0 6 3 8	18	24	40		64	F-18	10 R	F-18	−10 4	4 8	NR	NR
74}	11 Dec 2200	7 0	23 27	2 2 1 7	6	12	60		—	F-6		F-6	−10 4	3 1	NR	NR
75	12 Dec 2200	9 0	48 37	4 2 3 6	N	N	27		22	MTNS		MTNS				MTNS
76 CYS	15 Dec 2200	10 0	>50 27	4 6 5 0	N	N	44		0	MTNS		MTNS				MTNS
77 TCC	16 Dec 1000	7 −15	>50 27	6 0 5 0	N	N	22		0	MTNS		MTNS				MTNS
78 CPR	16 Dec 2200	14 0	>50 16	5 3 5 0	N	N	18		38	MTNS		MTNS				MTNS
79	20 Dec 2200	4 9	35 23	0 0 3 9	12	24	43		—	MTNS		MTNS				MTNS
80}	21 Dec 2200	1 0	45 23	1 0 >5	N	N	35	15 16	40	33	S	S	−12 6	3 8	30	NR
81}	22 Dec 1000	3 −7	45 24	4 0 >5	N	N	44		40	MTNS		MTNS				MTNS
82	24 Dec 2200	4 0	25 7	0 7 1 0	6	6	18		—	F-6	—	F-6	−13 0	2 4	NR	NR
83}	27 Dec 1000	5 0	30 12	0 7 2 7	24	18	25		9	MTNS		MTNS				MTNS
84}	27 Dec 2200	6 0	35 9	1 2 3 3	12	18	30		—	MTNS		MTNS				MTNS
85 II	1952 25 Jan 1000	7 4	35 4	1 5 2 5	N	18	38		22	MTNS		MTNS				MTNS
86	28 Jan 1000	7 0	25 23	2 2 2 4	6	12	43			F-6	—	F-6	−8 0	3 5	NR	NR
87	29 Jan 2200	3 −5	35 17	3 1 4 0	12	12	(15)			MTNS		MTNS				MTNS
88}	4 Feb 2200	0 −5	35 21	3 2 4 0	N	12	35	5 11	25	24	S	S	−7 3	4 2	24	30
89}	5 Feb 1000	2 −5	35 22	3 2 4 0	N	12	32	7 9	22	23	S	S	−11 0	2 9	12	NR
90}	6 Feb 1000	4 −3	35 23	2 0 4 0	N	36	27	15 8	30	25	S	S	−17 3	2 3	30	NR
91}	6 Feb 2200	5 −8	38 22	4 6 4 7	N	N	27	13 11	32	27	S	S	−19 4	2 0	NR	NR
92}	7 Feb 1000	7 −7	39 16	5 2 4 7	N	N	42	20 22	38	42	S	S	−5 8	5 6	24	24
93}	7 Feb 2200	9 −6	38 15	6 8 4 6	N	N	36	15 27	40	42	S	S	−2 8	6 2	12	18
94	9 Feb 2200	15 −5	45 17	5 0 4 0	N	N	48	14 30	44	42	10 L	S	−7 12	6 0	NR	24
95}	26 Feb 1000	5 −2	40 18	1 5 5 0	N	N	23	22 45	30	33	20 R	S	−13 0	2 5	NR	NR
96}	26 Feb 2200	9 0	41 23	4 0 5 0	N	N	25	15 23	40	33	20 R	S	11 4	3 6	24	NR
97}	27 Feb 1000	5 −6	30 17	4 2 3 0	12	36	28		27	28	30 R	S	0 3	5 7	12	24
98}	27 Feb 2200	4 −6	33 12	3 8 3 3	30	36	25			25		S	3 4	6 4	0	18
99	23 Mar 2200	4 −2	38 20	1 3 5 0	N	N	30	9 6	19	20	S	S	−12 2	3 0	30	NR
100	25 Mar 1000	4 0	24 13	0 7 4 5	30	6	28		20	MTNS		MTNS				MTNS

Case Nos. connected by "}" indicate successive 12 hour positions of the same cyclone.
Category II cyclones have been indicated by "II" following Case No.
In cases of twin-low-centers, location of cell has been indicated by station call letters after Case No.

APPENDIX IV. Category II cyclones — development and recurvature.

Case No.	Date	Amplitude in ° Lat. w	e (y)	f	Insta-bility Contract (c)/(s)	Advective Term 850 mb (d)	Half Wave-length (e)	Ampli-tude (f)	Stages 1/2 (g)/(h)	Hours Before Filling Actual (i)	Hours Before Filling Fcst (j)	Time of Recurva-ture Actual (w)
101	1947 9 Nov 1000	22	5	7	7	1	50	24	1.9/>5	30	N	0
102	13 Dec 2200	10	1	7	0	[illegible]	50	16	3.0/>5	42	N	6
103	28 Dec 2200	9	2	15	10	−9	50	20	>7/>5	N	N	12
104	1948 18 Feb 2200	13	2	5	12	−10	50	16	5.7/>5	N	N	0
105	11 Nov 2200	14	1	1	10	−3	30	14	6.0/3.0	N	N	0
106	28 Nov 2200	7	1	1	7	−7	35	5	5.3/2.7	N	48	0
107	1949 14 Jan 1000	6	2	16	9	−2	45	19	4.5/>5	N	N	12
108	23 Feb 1000	4	2	8	8	−10	37	9	6.8/3.5	N	N	0
109	5 Dec 2200	4	2	10	14	−3	40	12	5.5/4.0	N	N	0
110	1950 7 Feb 2200	5	2	8	5	−4	48	11	3.0/4.5	N	N	0
111	17 Mar 2200	7	1	6	11	0	37	11	5.0/3.7	N	N	18
112	22 Mar 2200	7	5	14	5	−6	27	16	4.0/2.3	42	24	0
113	5 Nov 2200	15	2	6	6	−7	33	19	4.7/3.5	48	N	6
114	4 Dec 1000	17	2	7	8	−9	39	22	6.6/5.0	N	N	36
115	30 Dec 2000	17	3	5	5	−8	43	19	4.6/5.0	N	N	12
116	1951 2 Jan 2200	(25)	2	2	7	0	39	(25)	2.0/(4.5)	24	42	NR
117	4 Jan 1000	3	1	4	7	2	42	6	1.6/3.4	N	24	18
118	26 Jan 1000	5	1	10	10	−18	(44)	14	5.5/(4.8)	30	N	6
119	22 Mar 2200	14	2	7	6	−6	50	19	4.5/>5	N	N	0
120	26 Mar 2200	8	5	8	10	−1	50	11	4.8/4.6	N	N	18

(c), (d), (e), (f), (g), (h), (i), (j), (w), refer to Appendix II Table 2 for legend.
(y) For definition of amplitude determinants, see the introduction.
(s) The axis for determining this parameter is perpendicular to the past track of the cyclone.

APPENDIX V. Table 1. Category III cyclones -- original data sample.

(Data in parentheses estimated, and believed correct)

Case No.	Date		Lowest Central Pressure	AT 500-MB LEVEL: Distance Up-Contour to NW Flow (a)	AT 500-MB LEVEL: Height of Contour Over Low (b)	AT 500-MB LEVEL: Location of Closed Low (c)	700-mb Half Wave-length (d)	Intensity Count: I	Intensity Count: 30-hr	Intensity Count: Class (e)
201	1947	21 Dec 1000E	1012 mb	450	—	-		10	7	NC
202		30 Dec 2200	999	—	183	450 WNW	22	16	(29)	D
203	1948	23 Feb 1000	992	—	178	300 WNW	25	18	14	NC
204		26 Feb 2200	998	—	183	400 SW	14	14	24	D
205		3 Nov 1000	996	—	181	—	15	10	16	D
206		17 Nov 1000	998	—	183	—	15	14	22	D
207		26 Nov 2200	1002	575	—	—	-	12	14	NC
208		11 Dec 1000	994	—	171	—	17	12	15	NC
209	1949	1 Jan 1000	998	—	175	500 NW	12	13	16	NC
210		10 Feb 2200	994		176	700 W	16	20	21	NC
211		20 Mar 1000	996	-	184	—	16	15	16	NC
212		10 Nov 1000	998	—	179	—	22	6	12	D
213		9 Dec 2200	990	—	178	—	(20)	16	24	D
214		15 Dec 2200	1002	900	—	—	—	14	13	NC
215		18 Dec 2200	1002	550	—	—	—	14	11	NC
216		24 Dec 1000	996	—	177	—	15	20	16	NC
217	1950	7 Jan 2200	1008	> 1200	—	—	—	12	T	FT
218		9 Jan 1000	994	—	178	—	15	16	36	D
219		11 Jan 1000	1002	1200	—	—	—	14	T	FT
220		14 Jan 1000	994	—	175	650 NW	18	24	24	NC
221		11 Feb 1000	1002	750	—	—	—	10	10	NC
222		5 Mar 2200	990	—	182	—	12	22	33	D
223		11 Mar 2200	998	—	183	—	37	20	T	FT
224		25 Mar 2200	980	—	182	—	22	22	28	D
225		1 Dec 1000	996	—	179	—	(18)	12	15	NC
226		1 Dec 2200	996	—	184	—	18	11	13	NC
227		5 Dec 1000	1006	500	—	—	—	9	10	NC
228		31 Dec 1000	994	—	178	—	13	16	12	NC
229	1951	1 Jan 1000	999	—	183	500 WNW	27	10	12	NC
230		15 Jan 2200	982	—	171	—	15	24	17	F
231		29 Jan 1000	1008	950	—	—	—	19	13	F
232		29 Jan 2200	1004	675	—	—	—	21	14	F
233		10 Feb 2200	1002	> 1200	—	—	—	14	T	FT
234		12 Feb 1000	1002	1000	—	—	—	13	T	FT
235		19 Feb 1000	1006	550	—	400 W	—	10	20	D
236		5 Mar 1000	990	—	175	—	24	19	T	FT
237		9 Mar 1000	1002	1000	—	—	—	17	9	F
238		15 Mar 2200	984	—	173	—	12	25	20	F
239		16 Mar 2200	994	—	183	—	11	13	17	NC

(a) Measured in miles, upstream, usually to contour trough west of cyclone.
(b) In hundreds of feet.
(c) Distance in miles from cyclone to closed 500-mb low. Direction indicated.
(d) Measured in degrees of latitude from trough west of low to ridge line east along latitude line through low center.
(e) [illegible]

APPENDIX V. Table 2. Control group data for Category III cyclones.

(Data in parenthesis estimated, and believed correct)

Case No. (g)	Date	Lowest Central Pressure	AT 500-MB LEVEL: Distance Up-Contour to NW Flow (a)	AT 500-MB LEVEL: Height of Contour Over Low (b)	AT 500-MB LEVEL: Location of Closed Low (c)	700-mb Half Wave-length (d)	I_0	Intensity Count 30-hr	Class (e)
240	1951 21 Nov 1000E	1004 mb	>1200			-	10	T	FT
241	21 Nov 2200	1006	>1200			-	10	T	FT
242	2 Dec 1000	995		179		23	13	23	D
243	18 Dec 2200	990		176	700 NW	15	24	12	F
244	19 Dec 1000	990		177	700 NW	20	20	12	F
245	19 Dec 2200	994		179		26	15	19	NC
246	23 Dec 2200	1010	600	-		-	10	9	NC
247	24 Dec 1000	1008	900			–	13	11	NC
248	30 Dec 1000	994		174		23	16	20	NC
249	1952 7 Jan 1000	1002	900			--	11	9	NC
250	13 Jan 2200	994		180	-	22	15	24	D
251	20 Jan 2200	996		178		16	20	25	D
252	21 Jan 1000	996		179	-	14	19	25	D
253	2 Feb 1000	998		183	-	15	15	12	NC
254	2 Feb 2200	992		182	-	20	18	11	F
255	17 Feb 2200	1000	700		800 NW	–	13	22	D
256	18 Feb 1000	999		182	--	18	17	19	NC
257	21 Feb 2200	1010	800		--	-	8	T	FT
258	2 Mar 1000	996		180	500 NW	30	11	14	NC
259	8 Mar 1000	1008	1000	-	600 WNW	–	7	14	D
260	8 Mar 2200	998		184	600 WNW	(28)	10	13	NC
261	9 Mar 1000	996		182	500 WSW	20	11	23	D
262	11 Mar 2200	990		178	600 NW	15	22	19	NC
263	13 Mar 2200	1002	400			—	10	T	FT
264	17 Mar 2200	994	--	180	300 NW	15	14	16	NC
265	19 Mar 2200	1004	>1200		—	—	8	T	FT
266	20 Mar 1000	(1000)	400		500 NW	--	12	15	NC
267	2 Mar 2200	999	--	183	500 NW	25	13	20	D

(a), (b), (c), (d), (e) Same as for preceding table.
(g) Successive positions of the same cyclone are considered independent cases, and are connected with bracket.

APPENDIX VI. Data, Category IV cyclones.

Date	Time	Lat. Low	Initial Intensity	Max. Intensity	500 mb Sharp.	Temp. 1000 NW	500 Temp. Factor	850 Advect. Factor	850 Temp. Factor	Steering 700 mb	30 hr. Dir.	30-hr. Speed
Nov 1947												
4	2200	43	9	10	220	10	7	1.6	1	78	35	19
14	2200	39	14	15	780	15	9	2.9	4	21	53	17
Dec 1947												
2	2200	48	14	16	420	16	3	3.0	7	68	69	32
7	1000	42	17	27	520	12	9	5.6	9	55	54	32
14	2200	30	11	20	1530	15	4	0.8	10	20	30	47
15	1000	35	15	22	1040	19	9	2.6	10	0	35	46
30	1000	41	12	12	1140	20	0	2.2	14	66	75	22
Jan 1948												
3	1000	42	7	12	330	13	1	5.5	−7	90	98	25
11	1000	42	18	21	490	7	6	4.3	−5	50	69	35
15	2200	45	21	22	980	6	3	7.6	2	68	57	24
Feb 1948												
12	1000	31	9	14	1150	18	−2	4.3	21	42	34	28
12	2200	35	8	21	1480	19	4	0.6	20	39	41	38
13	1000	39	12	23	1840	17	8	4.0	26	42	44	50
Mar 1948												
15	1000	40	11	18	500	12	5	2.1	8	62	56	43
18	2200	38	12	24	700	19	6	3.9	8	46	50	55
20	2200	46	11	13	720	18	−3	1.2	9	67	87	27
26	1000	42	19	24	780	10	5	5.1	17	54	73	43
26	2200	42	19	24	780	8	8	4.4	16	45*	76	41
31	1000	42	18	19	720	15	5	1.1	13	8	29	32
Nov 1948												
1	2200	36	10	12	580	6	1	1.6	−2	18	47	11
2	1000	36	12	12	510	7	−1	5.3	0	17	15	13
4	2200	41	18	25	1120	12	3	2.8	15	27	25	14
8	2200	41	9	17	1390	18	3	1.4	10	46	30	25
25	2200	47	9	14	420	6	5	1.2	−2	25	77	27

* 500 mb

Times are those of the upper level chart.

APPENDIX VI. Data, Category IV cyclones. (Continued)

Date	Time	Lat. Low	Initial Intensity	Max. Intensity	500 mb Sharp.	Temp. 1000 NW	500 Temp. Factor	850 Advect. Factor	850 Temp. Factor	Steering 700 mb	30-hr. Dir.	30-hr. Speed
Jan 1949												
17	2200	27	7	37	1770	18	2	3.0	15	19	24	48
18	1000	36	12	37	1210	24	8	2.6	20	35	32	55
27	1000	37	17	25	1140	12	11	3.4	20	22	47	43
Feb 1949												
7	2200	44	11	20	740	17	15	6.5	7	58	57	33
8	1000	47	14	20	570	13	8	2.9	9	80	62	38
23	2200	45	15	21	310	8	6	11.0	1	67	85	24
Mar 1949												
24	1000	41	21	22	1120	7	10	6.3	13	23	35	29
26	1000	40	14	16	1210	5	1	3.0	12		53	31
26	2200	42	15	17	1040	9	6	7.6	8	39*	60	37
Nov 1949												
11	2200	38	11	17	980	9	4	2.8	11	34	37	25
24	1000	41	17	17	1250	16	−3	5.0	−8	66	74	32
Dec 1949												
6	1000	42	16	19	290	16	3	1.7	−5	73	77	33
21	1000	37	13	20	1350	18	5	4.1	19	37	37	37
26	2200	39	4	24	1020	20	2	3.5	9	50	44	40
27	1000	45	14	24	1160	18	14	6.4	9	42	57	37
Jan 1950												
5	2200	36	8	16	1170	25	7	1.4	18	53	59	38
9	2200	44	15	34	680	20	11	10.1	16	54	54	40
17	1000	43	16	27	320	21	0	11.2	18	74	66	48
Feb 1950												
8	1000	38	11	17	350	16	5	3.5	7	57	56	43
8	2200	42	17	19	260	13	6	2.1	−1	60	60	40
10	2200	47	13	13	840	4	−7	2.3	1	62	75	25
21	2200	37	13	16	670	16	3	6.0	5	68	54	30
24	1000	43	15	23	1260	12	3	13.2	7	65	63	26
Mar 1950												
11	1000	42	11	12	520	14	11	2.9	15	78	75	45
19	1000	36	12	12	950	2	−5	4.6	6	17	45	13
19	2200	37	11	11	670	5	−4	2.4	3	—	49	14
27	2200	47	18	21	900	8	5	3.7	11	—	42	35

* 500 mb

Times are those of the upper level charts.

APPENDIX VI. Data, Category IV cyclones. (Continued)

Date/Time	Lat. Low	Initial Intensity	Max. Intensity	500 mb Sharp.	Temp. 1000 NW	500 Temp. Factor	850 Advect. Factor	850 Temp. Factor	Steering 700 mb	30-hr. Dir.	30-hr. Speed
Nov 1950											
1 1000	45	13	15	370	17	10	2.0	12	62	68	32
3 1000	34	9	18	1410	19	1	5.8	15	44	42	23
15 1000	42	14	25	420	17	12	6.8	8	52	56	27
15 2200	45	21	25	580	17	12	5.9	7	48	58	26
19 2200	40	21	25	640	25	6	6.9	10	48	46	40
Dec 1950											
2 1000	44	13	14	870	15	4	2.2	16	57	48	15
Jan 1951											
2 2200	36	10	17	1310	11	3	4.4	7	47	44	34
3 1000	41	13	23	990	17	12	3.1	10	36	57	37
3 2200	44	16	23	930	28	14	5.0	15	49	66	39
5 2200	41	11	12	590	18	−2	7.3	5	70	69	46
6 2200	34	10	20	840	15	5	8.7	14	65	56	47
7 1000	37	14	22	1210	14	9	5.8	17	56	47	41
10 1000	37	10	10	640	7	3	4.7	4	66	58	41
13 2200	35	12	22	1180	14	9	3.0	6	50	47	36
14 1000	37	14	25	1140	17	6	3.7	6	45	50	40
14 2200	43	16	25	1070	17	12	1.0	2	49	57	32
19 2200	37	13	23	570	22	9	2.6	9	70	55	40
20 1000	41	21	26	960	17	14	8.7	16	55	57	41
27 2200	35	9	12	590	22	0	4.6	6	77	58	42
Feb 1951											
1 1000	41	20	20	1520	25	15	5.4	31	37	49	45
15 1000	32	6	12	840	6	0	2.6	11	4	4	27
25 2200	43	12	24	440	15	14	1.3	9	33	65	25
28 1000	41	21	21	430	15	15	3.9	6	43	60	27
Mar 1951											
2 2200	41	17	26	760	19	19	6.6	16	47	38	32
11 1000	34	11	11	340	15	0	5.7	3	55	65	11
17 1000	37	14	21	920	14	−2	4.4	10	52	22	23
17 2200	38	14	22	1120	15	1	3.0	11	27	0	25
18 1000	43	21	22	1130	14	2	5.3	12	0	0	17
23 1000	40	21	24	670	14	6	9.1	8	55	53	27
28 2200	39	13	15	880	12	1	2.7	10	26	25	13

Times are those of the upper level charts.

APPENDIX VI. Data, Category IV cyclones. (Concluded)

Date	Time	Lat. Low	Initial Intensity	Max. Intensity	500 mb Sharp.	Temp. 1000 NW	500 Temp. Factor	850 Advect. Factor	850 Temp. Factor	Steering 700 mb	30-hr. Dir.	30-hr. Speed
Nov 1951												
5	2200	33	13	18	720	17	0	1.8	6	62	29	26
13	1000	42	18	27	1010	12	13	2.5	10	25	28	13
15	2200	36	11	14	730	20	4	4.9	14	57	56	42
25	2200	43	15	27	920	18	−4	3.2	−1	55	70	35
Dec 1951												
3	1000	46	21	24	750	11	7	4.2	7	30	45	24
8	1000	32	9	11	1000	24	9	2.8	14	40	51	56
8	2200	39	9	17	780	20	4	1.5	20	54	65	45
14	1000	37	18	23	970	30	2	6.5	9	62	60	53
20	1000	36	14	19	1390	16	−2	3.2	19	62	45	33
Jan 1952												
7	2200	41	14	14	430	10	7	3.1	−2	59	60	23
9	1000	34	7	22	650	24	3	7.3	9	48	72	43
15	1000	47	19	23	510	18	7	4.0	2	67	72	35
18	2200	40	17	20	630	13	7	2.1	3	65	70	45
19	1000	41	17	21	660	10	10	4.4	3	56	62	40
27	2200	31	9	20	820	19	7	2.9	6	60	55	57
Feb 1952												
3	2200	38	10	14	770	10	2	2.2	7	50	42	34
6	2200	42	8	13	750	7	−7	1.8	1	77	78	31
8	1000	42	20	20	5[illegible]0	15	−8	6.8	−4	66	74	41
13	1000	37	11	11	850	8	5	4.8	4	43*	fills	fills
19	1000	42	20	20	460	19	5	5.2	8	3[illegible]*	62	16
26	1000	30	11	26	1320	18	6	3.2	12	60	49	37
29	1000	35	14	25	370	23	−1	11.5	3	68	70	47
29	2200	36	18	24	510	22	0	5.6	5	62	60	40
Mar 1952												
3	1000	37	13	20	920	17	5	2.1	12	46*	52	32
10	1000	35	18	29	1300	20	8	4.6	2	32	52	39
18	1000	39	19	19	1400	9	9	3.3	5	0*	39	25
21	2200	36	13	25	1390	22	13	3.0	16	49	7	22
22	2200	41	21	26	1320	16	18	7.5	19	25*	36	17
25	1000	39	6	7	1020	5	1	1.4	3	64	62	30
25	2200	41	7	7	790	6	0	0.6	3	57	46	26
31	1000	40	8	20	470	14	8	1.9	4	55	35	27

* 500 mb

Times area those of the upper level charts.

APPENDIX VII. Table 1. Catalog for Category I surface cold fronts independent data (53 computations).

Date	Time	Lateral Frontal Reference Point	Geostrophic Wind 700-mb	Geostrophic Component 700-mb	Thermal Dist.	Forecast Speed	Observed Speed
2 Dec 50	1000E	37	47	22	1500	13	17
		33	37	18	900	17	21
2 Dec 50	2200E	41	55	20	950	17	17
		36	37	17	800	17	23
		28	28	19	600	20	25
5 Dec 50	2200E	40	25	14	200	20	17
		33	25	19	350	23	22
		27	48	30	300	32	24
9 Dec 50	1000E	31	45	37	400	36	29
11 Dec 50	1000E	33	30	30	300	32	20
		30	25	21	650	21	11
15 Dec 50	1000E	41	50	40	350	37	35
		36	45	40	200	38	35
		31	25	15	450	18	13
31 Dec 50	2200E	42	37	20	1500	11	10
5 Jan 51	2200E	36	35	15	300	20	17
6 Jan 51	2200E	33	46	30	500	30	30
		30	40	25	500	27	26
9 Jan 51	2200E	33	36	25	450	27	27
19 Jan 51	2200E	41	48	12	500	15	22
		37	38	14	500	17	22
20 Jan 51	1000E	38	55	30	450	30	30
		34	48	22	500	24	25
23 Jan 51	1000E	42	37	33	400	33	25
		37	37	34	150	36	25
		31	35	23	400	26	20
28 Jan 51	2200E	39	40	5	1200	4	9
		34	35	5	1200	4	9
		30	22	0	1200	0	9
1 Feb 51	1000E	37	80	40	450	22	25
		33	65	36	600	26	18
		30	40	22	600	23	17
6 Feb 51	1000E	41	35	31	300	33	33
		37	35	27	350	30	33
		26	38	33	500	32	39
12 Feb 51	1000E	46	48	12	800	13	12
		39	34	0	400	8	10
13 Feb 51	1000E	37	30	0	500	7	7
19 Feb 51	2200E	30	25	17	400	21	25
3 Mar 51	2200E	40	70	55	850	30	30
		35	40	20	850	19	15
		30	30	0	450	7	8
6 Mar 51	2200E	44	37	26	300	29	30
		40	35	13	850	13	12
17 Mar 51	2200E	36	45	20	1500	11	11
1 Nov 50	1000E	39	48	25	1500	15	14
		35	30	12	1500	5	9
3 Nov 50	2200E	33	45	26	800	25	27
		26	30	23	500	25	26
15 Nov 50	1000E	37	48	24	550	25	20
		34	44	18	1000	15	16
16 Nov 50	1000E	42	50	40	950	30	25
		36	50	24	850	[illegible]	[illegible]

APPENDIX VII. Table 2. Catalog for Great Plains wedge-fronts open trough category cases independent data (28 cases).

Date	Time	Lateral Frontal Reference Point	North	West	A	Forecast Speed	Observed Speed
21 Nov 51	2200E	37.5	12	0	10	13	12
22 Nov 51	2200E	33	0	3	0	7	7
25 Nov 51	2200E	26	16	8	1	17	11
20 Dec 51	1000E	32	16	12	35	28	[illegible]
22 Dec 51	2200E	35	17	2	12.5	17	15
31 Dec 51	2200E	33.5	19	6	0	17	19
1 Jan 52	1000E	31	8	4	4	6	8
2 Jan 52	1000E	28	7	3	4	5	9
10 Jan 52	2200E	48	16	0	12	15	16
12 Jan 52	1000E	37	3	−4	0	0	0
16 Jan 52	2200E	41	12	−8	28	21	23
17 Jan 52	2200E	31	−4	−5	−2	0	0
19 Jan 52	2200E	32	8	10	−2	0	2
22 Jan 52	1000E	27	20	0	20	21	19
25 Jan 52	1000E	36.5	9	−4	10	9	9
25 Jan 52	2200E	36.5	12	1	12	15	15
26 Jan 52	1000E	32.5	16	8	−2	17	16
26 Jan 52	2200E	28.5	18	13	2	21	22
27 Jan 52	1000E	35	14	15	15	12	0
8 Feb 52	1000E	32.5	12.5	−9	0	4	1
13 Feb 52	2200E	35.5	12	10	−2	16	15
27 Feb 52	2200E	37.5	18	−13.5	9	8	6
28 Feb 52	1000E	35	18	−10	9	10	11
29 Feb 52	1000E	31.5	15	−2	0	10	12
14 Mar 52	2200E	31.5	6	−3	−10	1	18
26 Mar 52	1000E	36.5	18	12	6	21	18
26 Mar 52	2200E	32	7	3	14	15	14
27 Mar 52	1000E	29	15	−3	3	10	8

APPENDIX VII. Table 3. Catalog for Great Plains wedge-fronts closed low category cases independent data (30 cases).

Date	Time	Lateral Frontal Reference Point	Overlay Speed	Observed Speed
1 Nov 51	1000E	26	15	20
4 Nov 51	2200E	34	24	22
5 Nov 51	1000E	31	32	28
15 Nov 51	1000E	31.5	31	25
20 Nov 51	2200E	45.5	17	20
21 Nov 51	1000E	41	12	14
22 Nov 51	1000E	35	8	8
23 Nov 51	1000E	32	11	4
13 Dec 51	2200E	36	32	39
24 Dec 51	2200E	35	24	21
30 Dec 51	1000E	43	14	21
30 Dec 51	2200E	39	16	15
31 Dec 51	1000E	27.5	25	16
1 Jan 52	2200E	28.5	19	9
11 Jan 52	1000E	43	5	10
11 Jan 52	2200E	42	6	4
21 Jan 52	1000E	37.5	25	28
21 Jan 52	2200E	32.5	23	27
14 Feb 52	1000E	31	24	22
24 Feb 52	1000E	34	31	28
24 Feb 52	2200E	29	32	30
28 Feb 52	2200E	34	24	19
29 Feb 52	2200E	27	4	0
2 Mar 52	2200E	33.5	28	30
3 Mar 52	1000E	32.5	28	36
8 Mar 52	2200E	34	26	20
19 Mar 52	2200E	35.5	12	3
20 Mar 52	1000E	34	17	6
20 Mar 52	2200E	34	21	20
21 Mar 52	1000E	34	30	30

APPENDIX VII Table 4. Catalog for east coast wedge-fronts dependent data (30 cases).

Date	Time	Lateral Frontal Reference Point	West	East	850	Forecast Speed	Observed Speed
10 Nov 49	2200E	44	-60	-10	17	12	14
11 Nov 49	1000E	42	-30	100	17	16	16
11 Nov 49	2200E	40	-35	-70	17	15	[illegible]
14 Dec 49	1000E	30	-40	00	10	5	3
14 Dec 49	2200E	30	00	00	10	8	5
5 Jan 50	1000E	37	-140	70	5	0	0
11 Jan 50	1000E	32	-80	-40	10	4	0
18 Jan 50	2200E	37	10	70	23	20	22
19 Jan 50	1000E	35.5	00	75	25	20	20
19 Jan 50	2200E	33.5	00	00	20	19	18
23 Jan 50	1000E	42	-30	00	11	9	14
23 Jan 50	2200E	41	-130	00	17	5	5
27 Jan 50	1000E	34	-75	00	15	9	9
27 Jan 50	2200E	32	-40	00	14	10	5
30 Jan 50	1000E	37	-100	70	10	2	3
3 Feb 50	1000E	31	00	00	17	16	11
6 Feb 50	2200E	38.5	35	35	17	19	23
7 Feb 50	1000E	35.5	35	00	14	16	13
7 Feb 50	2200E	32	00	-30	14	16	3
11 Feb 50	2200E	30.5	-220	00	9	0	0
29 Jan 51	2200E	36	-60	80	20	11	12
5 Feb 51	2200E	42.5	00	-90	6	3	6
14 Feb 51	1000E	38.5	-30	-140	17	19	20
14 Feb 51	2200E	35	-75	-75	15	11	14
15 Feb 51	1000E	31	120	-70	8	2	3
2 Mar 51	2200E	34	-250	-75	20	0	0
3 Mar 51	2200E	33	00	-25	9	7	6
7 Mar 51	2200E	36	40	-50	10	11	13
8 Mar 51	1000E	34	60	-60	12	15	15
17 Mar 51	2200E	35.5	-150	-120	13	4	7

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